ORBITAL TRANSFER VEHICLE

CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY

FINAL REPORT – PHASE I
VOLUME VII

INTEGRATED TECHNOLOGY DEVELOPMENT PLAN
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FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton and during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

VOL.	I	Executive Summary (Rev. A)
VOL.	II	OTV Concept Definition & Evaluation
		Book 1 - Mission Analysis & System Requirements
		Book 2 - Selected OTV Concept Definition - Phase I
		Book 3 - Configuration and Subsystem Trade Studies
		Book 4 - Operations and Propellant Logistics
VOL.	III	System & Program Trades
VOL.	IV	Space Station Accommodations
VOL.	V	WBS & Dictionary
VOL.	VI	Cost Estimates
VOL.	VII	Integrated Technology Development Plan
VOL.	VIII	Environmental Analysis
VOL.	IX	Implications of Alternate Mission Models and Launch Vehicles

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ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
AFE	Aeroassist Flight Experiment
AGE	Aerospace Ground Equipment
AL	Aluminum
ASE	Airborne Support Equipment
A/T	Acceptance Test, Auxiliary Tank
AUX	Auxiliary
AVG	Average
B/B	Ballute Brake
B/W	Backwall
CDR	Critical Design Review
CPU	Central Processing Unit
CUM	Cumulative
DAK	Double Aluminized Kapton
DDT&E	Design, Development, Test & Evaluation
DELIV	Delivery
DMU	Data Management Unit
DoD	Department of Defense
EPS	Electrical Power System
FACIL	Facility
FFC	First Flight Certification
FLTS	Flights
FOSR	Flexible Optical Surface Reflector
FRCI	Fiber Refractory Composite Insulation
F.S.	Fail Safe
FSI	Flexible Surface Insulation
FTA	Facilities Test Article
GB	Ground Based
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GRD	Ground
IOC	Initial Operational Capability
IRU	Inertial Reference Unit
IUS	Inertial Upper Stage

JSC	Johnson Space Center
L/B	Lifting Brake
LCC	Life Cycle Cost
L/D	Lift to Drag
MGSS	Mobile GEO Service Station
MLI	Multilayer Insulation
MPS	Main Propulsion System
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
OMV	Orbital Maneuvering Vehicle
OPS	Operations
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module, Propulsion Avionics Module
PDR	Preliminary Design Review
PFC	Preliminary Flight Certification
P/L	Payload
PROD	Production
PROP	Propellant
RCS	Reaction Control System
REF	Reference
RGB	Reusable Ground Based
R&R	Remove & Replace
RSB	Reusable Space Based
RSI	Reusable Surface Insulation
SB	Space Based
S/C	Spacecraft
SCB	Shuttle Cargo Bay
SIL	Systems Integration Laboratory
STA	Structural Test Article
STG	Stage
STS	Space Transportation System
T/D	Turndown
TDRS	Tracking Data Relay Satellite
TPS	Thermal Protection System
TT&C	Telemetry, Tracking and Control
WBS	Work Breakdown Structure

1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from $12,000 to $24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that a space station is a firm national commitment, and a refinement in mission projections out to 2010.

During the nineteen-month technical effort the specific issues addressed were:

a. What are the driving missions?
b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?
c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?
d. How extensive are the orbital support systems in terms of propellant logistics and space station accommodations?
e. Where should the OTV be based?
f. How cost effective is a reusable OTV program?
g. What are the implications of using advanced launch vehicles?

1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV mission model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

1.4 DOCUMENT CONTENT

This document presents the technology plan associated with an advanced OTV program. By in large the plan addresses technology areas applicable to either a reusable ground based (GB) OTV or reusable space based (SB) OTV. In addition, technology unique to SB OTV's is also discussed. Section 2.0 presents an assessment of each technology area. Section 3.0 defines the technology plan including schedule and resource requirements. Section 4.0 presents an overall summary.

2.0 TECHNOLOGY ASSESSMENT

During the course of this study several technology areas were identified where current technology areas do not appear to meet the projected OTV requirements. This volume presents a technology development plan for bringing these areas up to a level consistent with OTV needs, including tasks definition, task objectives, requirements, mode of accomplishment, schedules, and resource requirements.

Technology areas addressed in this plan are listed in table 2-1, along with a criticality assessment of each for each OTV concept studied. The critical technologies are divided into two categories: enabling and high payoff. Enabling technologies are those that are essential for the feasibility of the concept, and high payoff technologies are those that significantly improve the performance of the concept. The technologies have not been ranked relative to each other in terms of criticality because this depends on the aerobraking and basing mode that is selected.

Three technology areas shown in table 2-1 apply only to space based systems. These are cryogenic fluid management, which is concerned with transferring, venting, and measuring cryogens at low "g"; cryogenic tankage, which concerns the potential for an explosive rupture due to debris or meteroid impact while based at a space station; and space station accommodations.

All of the technology areas impact each of the aero braking concepts. Accordingly, we recommend the technology work to begin as soon as possible rather than wait for a final decision regarding aerobraking and basing mode.

2.1 AEROTHERMAL METHODS

The efficient design of an OTV TPS and structure requires an accurate and reliable determination of the thermal environment to which it will be subjected. Underpredicting this environment could limit reuse capability and even result in loss of the vehicle. Overly conservative predictions result in excessive TPS weight and non-optimal configuration, which adversely impacts system performance and costs. Consequently, improvements in the accuracy of aerothermal predictions translate into improved system performance and reliability.

Existing analysis methods and test data are clearly inadequate for OTV. Uncertainties in aerothermal predictions are estimated to be $\pm$ 50 percent on windward surfaces, and $\pm$ 400 percent in base regions. Currently, estimates of heating due to non-equilibrium gas radiation range from much less than 1 BTU/ft^2 - sec to nearly 30

Table 2-1 Technology Criticality Assessment

	GROUND BASED	SPACE BASED		
TECHNOLOGY	BALLUTE	BALLUTE	LIFTING BRAKE	SHAPED BRAKE
Aerothermal Methods	H/P	H/P	H/P	H/P
Thermal Protection	E	E	E	H/P
Aerodynamics	H/P	H/P	H/P	H/P
Propulsion	H/P	H/P	H/P	H/P
Cryo Fluid management	N/A	E	E	E
Cryogenic Tankage	N/A	H/P	H/P	H/P
Guidance	H/P	H/P	H/P	H/P
Atmospheric Physics	H/P	H/P	H/P	H/P
Data Management System	H/P	H/P	H/P	H/P
Station Accomodations	N/A	H/P	H/P	H/P
Aeroassist Flight Exp	H/P	H/P	H/P	H/P

CODE

E - Enabling

H/P - High Payoff

N/A - Not Applicable

BTU/ft^2 - sec (black body) for the same OTV vehicle and trajectory, which compares with peak convective heating rates of 30 to 40 BTU/ft^2 - sec. We consider errors in heating rates on windward surfaces due to imperfections in methodology must be less than about $\pm$20 percent to insure a satisfactory thermal design, with $\pm$10 percent as a realistic goal.

Other deficiencies in our current data base are a lack of reliable gas reaction rate data, and analysis methods for treating rarefied flows and base heating.

2.2 THERMAL PROTECTION

The thermal protection system (TPS) is one of the most critical OTV technology items. The TPS must provide an aerodynamic surface capable of withstanding heat transfer rates of the order of 20 to 40 BTU/ft^2 - sec, while insulating the structure from the effects of this environment.

Two basic types of TPS are proposed for OTV: flexible surface insulation (FSI) and rigid surface insulation (RSI). High density refractory (HDR) is not proposed as the preferred TPS concept for any of the OTV concepts studied, but is retained as an alternative to RSI where RSI temperature capability is marginal. The projected operating limits of each TPS type and maximum heating rates predicted for each AOTV concept are shown in table 2.2. Heating rates are used as the measure of thermal capability instead of surface temperature because surface temperature is strongly dependent on optical properties, which vary from material to material.

It is clear from table 2-2 that substantial improvements in FSI thermal capability is required to meet minimal requirements, and improvements in RSI are needed for all candidate aeroassisted OTV concepts.

2.3 AERODYNAMICS

Current OTV configuration designs depend on the performance benefits of an aero-assist maneuver which occurs in the flight regime characterized by rarefied gas dynamics. The OTV is the first vehicle to be critically dependent on this flow regime for its design drivers. The configurations are large scale light weight rigid and/or flexible structure which provide high drag (large C_DA) with drag modulation or low lift-to-drag for trajectory control. These configurations are constrained by aeroelastic effects, minimum stability margins (ballute) and predetermined longitudinal trim attitudes. Consequently, accurate prediction methods for this flight regime are required to assure OTV mission success and minimize the design margins.

Table 2-2. TPS Heating Limits

AEROASSIST TPS TYPE	TPS LIFE (MISSIONS)	HEAT LIMITS (BTU/FT^2 – SEC)		
		CURRENT TECHNOLOGY	1990 TECHNOLOGY	
			NORMAL GROWTH	ACCELERATED GROWTH
FLEXIBLE SURFACE INSULATION (FSI)	5	4–6 (AFRSI)	30	50
	1	6–8	35	50
RIGID SURFACE INSULATION (RSI)	20	38 (FRCI)	50	90
HIGH DENSITY REFRACTORY (HDR)	20	70 (ACC)	90	150

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The existing aerodynamic data base from which the OTV design may draw includes flight and wind tunnel experience from programs such as Gemini, Apollo, Viking, Pioneer, Venus, Prime, Asset, and the Shuttle. Additional wind tunnel data is available from the many decelerator research programs, e.g., the attached inflatable decelerators for Mars Missions.

Although, a large body of data exist for OTV class of configurations very little is available for the design point for OTV which occurs at higher altitudes than for full entry missions and in the rarefied flow regime with viscous interaction and equilibrium/non- equilibrium effects being critical. Thus, adequate engineering methods and a technology data base need to be developed for this flight regime. This flow environment (Mach number, enthalpy, chemistry) is not fully simulated in current wind tunnels and future analysis will be based more on computational fluid dynamics. In rarefied flows, the viscous effects become more influential with significant increases in drag (and consequently reduced lift/drag) and changes in lift and pitching moments. The equilibrium/non-equilibrium flow field alters pressure, and force and moments as experienced on past re-entry vehicles.

Previous methods of analyzing wind tunnel data has relied on correlation factors which have been satisfactory for drag but unsatisfactory for other aerodynamic parameters. With the aerodynamics in this flight regime determining the vehicle design drivers, the aerodynamics analyses will rely more heavily on computational fluid dynamic (CFD) for guidelines and data correction.

For flexible structures flutter is a concern near maximum dynamic pressure. Flutter analyses of the flexible structures are completed using time variant CFD codes and structural models determined from material testing. A wind tunnel test of the flexible ballute may be necessary to evaluate the aerodynamic characteristic and to verify the flutter analysis. Jet counterflow is a promising means of modulating aerodynamic drag and requires analysis/testing of a complex flowfield.

Current activities which support the OTV design have been preliminary wind tunnel test of a variable drag ballute concept (Mach 20), a lifting brake (Mach 10), and a biconic configuration (Mach 6-10). Parabolized Navier Stokes codes are being developed for bionics and have been the verified by wind tunnel tests. Blunt body Navier Stokes codes have been used to analyze shaped brake (NASA-JSC) and a ballute (NASA-LaRC, Boeing).

There are currently a limited number of CFD codes which are applicable to the equilibrium/non-equilibrium effects predominant in the flowfield about current OTV configurations. The flowfield behind the bow shock is largely subsonic and viscous in nature and requires the application of a compressible Navier-Stokes code or viscous shock layer codes. An axisymmetric real gas time- asymptotic Navier Stokes code and an axisymmetric multi-pass marching viscous shock layer code with non-equilibrium effects is available from NASA Langley Aerothermodynamic Branch and a fully three dimensional time variant Navier-Stokes code with equilibrium chemistry is available from NASA Ames. Other CFD codes which may be readily available are restricted to perfect gas flow. Semi-empirical math model development for rarefied real gas equilibrium flow has been initiated by NASA.

A basic requirement exists to further develop engineering methods for this flight regime. However, these methods must be based on experimental data, benchmark type calculations, and analysis of existing flight data.

2.4 PROPULSION

The state-of-the-art in cryogenic engines is the RLIO-A-3-3A. It is a LO_X-LH_2 expander cycle engine of 16,500 lbf thrust with a chamber pressure of 400-psia and specific impulse of 446 sec. The turbomachinery is gear driven and has life suitable for two missions.

NASA is currently funding technology programs with Rocketdyne Division of Rockwell Intl., Aerojet Tech Systems, and Pratt & Whitney Div. of United Technologies for advanced engines. The programs are focused on performance and life enhancements in all engine areas: turbomachinery, thrust chambers, nozzles, health monitoring, controls, and maintainability. Results to date from those studies indicate that a specific impulse greater than 480 seconds is achievable at a thrust of 5,000 lbf which the current OTV studies found to be near optimum. As currently planned these advanced engine technologies would be validated with research engines by the late 1980's.

2.5 CRYOGENIC FLUID MANAGEMENT

Handling cryogenic oxygen and hydrogen at the space station will require significant advances in the state of the art low "g" fluid transfer. Surface tension screens are the only method identified for liquid acquisition which is applicable to the space station "g" environment. Surface tension devices have not been demonstrated effective for cryogenic fluids. Heat transfer to the screens during pressurization and fluid transfer could cause the screens to dry out and fail to function. Orbital test data are needed to establish performance characteristics of screen acquisition devices in large tanks.

Thermodynamic vent systems are expected to provide a satisfactory solution to the problem of venting cryogenic tanks in an orbital environment. The system to be flown on the Centaur G prime missions should verify this approach pending analysis of the flight data.

Vapor cooled shield provide improved performance of cryogenic tank insulation systems under conditions of continuous tank outflow. Intermittent flow through the vapor cooled shield vent system may degrade the system thermal control due to warming of the shields during no flow periods. Thorough analysis of this type system is needed to verify predicted boiloff rates.

Quantity gaging or two phase fluids in low "g" environments is uncertain and no satisfactory methods are identified at this time. Accurate gaging is needed to verify adequate loading of the OTV at the station before committing the mission.

2.6 CRYOGENIC TANKAGE

It is a well recognized and substantiated fact that meteoroid/space debris impacts to space systems must be anticipated and reflected in the design of those systems. A considerable effort has gone into developing analytical methods for predicting meteoroid and debris fluxes, impact probabilities, penetration/damage mechanics and penetration probabilities. Efforts are continuing along the lines of improving these methodologies and designing more efficient protection systems to resist penetration. However, the fact that pressurized propellant tanks within the meteoroid/debris environment constitutes a major safety hazard has not been adequately addressed.

Efforts to date have illustrated that the more efficient means of providing improved protection against impact or penetration is to provide a bumper or shield to breakup incoming particles and a backwall some distance away, to stop the resultant dispersed debris. It has also been common practice to balance the economic/operational impact of the probability of system loss against the economic/operational/performance impact of the weight of the protection system required to provide the corresponding probability of no penetration. In the case of propellant tankage this has typically been interpreted as no tank impact and the tanks are then designed for minimum weight without regard to potential implications of impact.

Existing methodologies appeared to be adequate to support this design approach, and 2219 aluminum is a well proven material available for tank wall construction.

Recent assessments of tankage/protection system designs with protection system thicknesses approaching the tank wall thickness indicate that; if the tank is impacted it will probably be penetrated, and if it is penetrated it will probably experience explosive rupture. Recognition that tankage explosive rupture can be much more adverse than mere loss of vehicle and payload demands a reassessment of the design approach and incorporation of corresponding design criteria addressing the probability of explosive rupture. One current approach to this problem is to eliminate the use of a separate backwall and design the pressure vessel wall to operate at a stress level that will result in a critical thru crack length of at least twice the nominal shield to tank wall standoff distance. This will eliminate the potential for explosive rupture resulting from right angle impacts producing dispersion cone half angles of up to 45 degrees in the nominal protection areas. However, impacts will usually not be at right angles to the surface, the effective standoff will be greater and the tank impact area width can be greater than twice the actual standoff distance. Also, economic design practices will dictate use of standoff distances in the between tanks areas which are much greater than the nominal values. Therefore a more comprehensive assessment of the problem is required. The end result of that assessment is not currently predictable and may result in significant design philosophy changes with attendant performance impacts. Improvements in the various methodologies may be required to keep the performance impacts within acceptable limits.

The implications of explosive rupture may not be too significant to the design of the ground based OTV but the implications to the design and operation of a space based OTV and on-orbit storage tanks will be relatively significant. If weight increases sufficiently there may be incentive for considering use of light weight tank construction materials, i.e., lithium aluminum or metal matrix composites.

2.7 GUIDANCE, NAVIGATION, AND CONTROL

Current technology OTV GN&C is a modified IUS system consisting of gamma guidance for the exoatmospheric portion plus an enhanced version of gamma guidance for the endoatmospheric portion. Navigation uses GPS plus an inertially aided stellar attitude determination. RCS thrusters are used for vehicle control (same as STS). Projected technology advances would include improving the adaptive guidance algorithm to constrain equilibrium heating and using improved inertial measuring units to reduce error buildup. If additional development funds were available, it is possible to develop a real-time optimal guidance system that functions in the atmosphere much the same as gamma guidance functions outside the atmospheres. This system will take into account atmospheric dispersions and heating constraints. It should be possible to develop a fully autonomous navigation system by 1995.

2.8 ATMOSPHERIC PHYSICS

Current technology for OTV atmospheric physics is the Global Reference Atmosphere Model (GRAM), and STS measured density profiles. Because of the unpredictability of the atmosphere and the sparseness of readily available data in the OTV region of interest, improvements are needed. Projected technology improvements include updating the GRAM mean and statistical data bases with existing atmospheric density data. If additional funds are available it will be possible to perform lidar experiments to obtain more data and to gain insight into the gravity wave structure. It should be possible to develop a forecasting capability using the expanded data base and correlation data of the thermosphere.

2.9 DATA MANAGEMENT SYSTEM

Improved redundancy management techniques are needed to provide the system reliability needed for OTV. Also, the size, weight, and power requirements of the DMS will have a substantial impact on OTV system weights and performance. Substantial improvements in all of these areas beyond what is possible with today's technology can be achieved through:

1. Distributed architecture,
2. fiber optic bus technology,
3. improved fault tolerance techniques,
4. advanced microprocessor hardware, and
5. improved packaging techniques.

Today, centralized system architectures are prevalent, but heirarchical federated system architectures are becoming more common. Fiber optic serial communications are widely used, and high speed fiber optic computer data buses with star coupler interfaces are in development. Several fiber optic bus protocols have been defined, including MIL-STD-1773 and IEEE 802.4. Implementation of these protocols in hardware are in development.

Currently, triple modular redundant computers are being developed. Hamming error detection and correction (EDAC) IC's are available, and both dedicated and pooled sparing techniques are in development.

The required microprocessors (F9450) are available, but require qualification for space applications. Static random access memories (RAM) are available to 16K densities, and electrically eraseable programmable read only memories (EEPROM) are available in densities to 32K. Higher densities of both devices are in development.

The current Boeing DMS breadboard design requires 15 ft^3, uses 2,000 watts, and weighs 500 lbm. No effort has yet been made to reduce the component count or power requirements.

2.10 STATION ACCOMODATIONS

In order to base an OTV on-orbit, several technology areas will have to be advanced. These areas are thermal protection system (TPS) replacement, automation of servicing, and vehicle assembly on-orbit. All space-based OTV concepts we have studied have some rigid RSI tile insulation. It is expected that some of these tiles will have to be replaced on orbit. The lifting brake concept requires periodic replacement of the flexible TPS, and the ballute concepts require installation of a new ballute prior to each mission.

Automation of some OTV servicing tasks is desirable to reduce Space Station crew time, and hence cost. Because of their repetitive and time-consuming nature, post-mission inspection of TPS and propellant transfer are good candidates for early automation.

The shaped brake OTV concept requires on-orbit assembly since the vehicle is too large to fit in the Space Shuttle.

2.11 AEROASSIST FLIGHT EXPERIMENT

To establish a technology development plan it has been found that much of the needed aerothermal, aerodynamics, and TPS data cannot be obtained using existing ground test facilities. For this reason, a Space Shuttle launched flight experiment has been recommended that would significantly benefit the aerothermal, thermal protection system, GN&C, atmospheric physics and aerodynamics development efforts.

The proposed aeroassist flight experiment (AFE) is not a technology item itself. However, the AFE will act as the carrier vehicle for a series of experiments. The vehicle should be a combination rigid blunt body and aeroassist device which can accept adapters to make it representative of the full scale aerobrake (ballute) or lifting brake. The data gained from this test(s) would be applicable to any aeroassisted OTV configuration.

3.0 TECHNOLOGY PLAN

3.1 AEROTHERMAL METHODS

3.1.1 Objective

The objective of this effort is to develop the analysis tools and data base required to define OTV aerothermal environments with the accuracy and reliability needed for TPS design. Goals are to reduce uncertainties in aerothermal predictions due to imperfections in methods to 10 percent on windward surfaces, and 40 percent in base regions as indicated in table 3.1-1. Since results are needed to support the TPS development activity, it is important that critical outputs from this program be available as early as possible.

3.1.2 Description

The recommended program consists of parallel efforts in the following three areas:

(1) Computational fluid dynamics (CFD).

(2) High temperature gas physics.

(3) Ground tests.

In addition, results from the AFE will be utilized to upgrade and validate methods.

3.1.2.1 Computational Fluid Dynamics.

Status. Great strides have been made in recent years in computational fluid dynamics (CFD) due to improvements in computer hardware, flow modeling, and computational algorithms. Three-dimensional viscous flow field solutions are now routine for supersonic flow fields using parabolized Navier-Stokes codes. Capability is much more limited for low L/D OTV type shapes, which are characterized by subsonic flow fields over most of the windward surface. Codes are available for solving the full Navier-Stokes equations for 2-dimensional and axisymmetric flows, but are relatively costly to use. Also, operational codes are not available for considering finite gas chemistry reaction rates for viscous flows over blunt bodies.

Plan. The ultimate goal is to develop a flow field code by 1988 that is capable of treating subsonic or supersonic flow fields, non-axisymmetric flows, non-equilibrium gas

Table 3.1-1. *Technology Goals — Aerothermal*

ITEM	TASKS	STATUS	GOALS
AEROTHERMAL METHODS DEVELOPMENT	• CFD DEVELOPMENT	• CODES APPLICABLE TO OTV ARE COSTLY AND GENERALLY LIMITED TO • AXI-SYMMETRIC FLOW • EQUILIBRIUM GAS • NO RADIATION COUPLING	• REDUCE UNDERTAINTIES HEATING PREDICTIONS TO: • 10% ON WINDWARD SURFACES • 40% IN BASE REGIONS
	• HIGH TEMPERATURE GAS PHYSICS	• INDEPENDENT PREDICTIONS OF NON-EQUILIBRIUM RADIATION DIFFER BY 2 ORDERS OF MAGNITUDE	
	• GROUND TEST	• VERY LITTLE HEAT TRANSFER DATA EXIST ON OTV SHAPES	

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chemistry, arbitrary surface catalysis, jet counterflows, and rarefaction effects. This goal cannot be achieved in a single step, but must evolve through several phases. The completion of each phase will improve the accuracy and confidence level of the AOTV aerothermal predictions.

The recommended approach for this effort is to:

(1) Continue development of improved computational algorithms and grid generation technique,

(2) Using results from the above, develop more efficient flow field codes, with emphasis on axisymmetric and non-axisymmetric blunt body flows,

(3) Expand the capability of these codes to include non-equilibrium gas chemistry, including radiation, and foreign gas jet counter flow, and

(4) Validate results by test.

3.1.2.2 High Temperature Gas Physics

The recommended approach is to continue and expand current NASA efforts to develop a better understanding of hot gas radiation. Tasks required for this are:

(1) To develop and verify analytical gas models accurately accounting for all significant gas species, chemical reactions and reaction rates, and radiative heat transfer,

(2) To establish and validate chemical rate and radiative transfer coefficients required by the analytical model, and,

(3) To integrate the gas models into an appropriate shock layer flow field code, coupling the kinetic and chemical terms to satisfy conservation of energy constraints.

Initially, fundamental gas property data needed for tasks 1 and 2 can be obtained from arcjet facilities and hypervelocity ballistic ranges. Ultimately, validation of the radiation predictions will require experimental data on reasonably sized models at enthalpies up to 20,000 BTU/lbm, which can only be obtained from flight tests.

3.1.2.3 Ground Tests

Wind tunnel and ballistic range tests are required to provide data needed to validate analytical tools, develop empirical prediction methods, and upgrade gas chemistry data. Conventional pebble bed heated hypersonic wind tunnel and shock tunnels are proposed for most of the heat transfer tests. Specific areas where heat transfer data are needed include:

(1) Rarefied flow effects.

(2) Real gas effects.

(3) Base regions, including wake impingement heating boundaries.

In addition, shock tubes and ballistic ranges are needed to generate reaction rates, radiation data, and other measurements needed for upgrading gas chemistry analytical models.

3.1.3 Schedule and Resdources

The key technology milestones for the aerothermal area are shown in figure 3.1-1. The resources required for the effort are presented in table 3.1-2.

3.2 THERMAL PROTECTION

3.2.1 Objectives

The primary objective of the TPS development program is to upgrade the maximum heating capability of FSI and RSI to meet the normal growth projections given previously in table 2.2, with a goal of achieving the accelerated growth capability. The accelerated growth heating limits exceed our current OTV heating predictions, but the added capability is needed to provide some margin for changes in TPS design requirements which may occur as the OTV design matures and due to modification in prediction methods. Also, the excess capability may permit reductions in vehicle size, which could translate into substantial reductions in system weight.

Other goals, which are given in table 3.2-1, include:

(1) Improve design and fabrication techniques for TABI type woven structures to:

  (a) Permit thinner blankets.

  (b) Vary blanket thickness.

(2) Increase the temperature capability of RSI/SIP bonds.

3.2.2 Description

3.2.2.1 Flexible Surface Insulation

Status. Silicon carbide fabrics have been successfully tested at convective heating rates to nearly 34 BTU/ft^2 - sec (ref. 5). Also, a vastly improved fabric structural concept, designated as tailorable advanced blanket insulation (TABI), has recently been

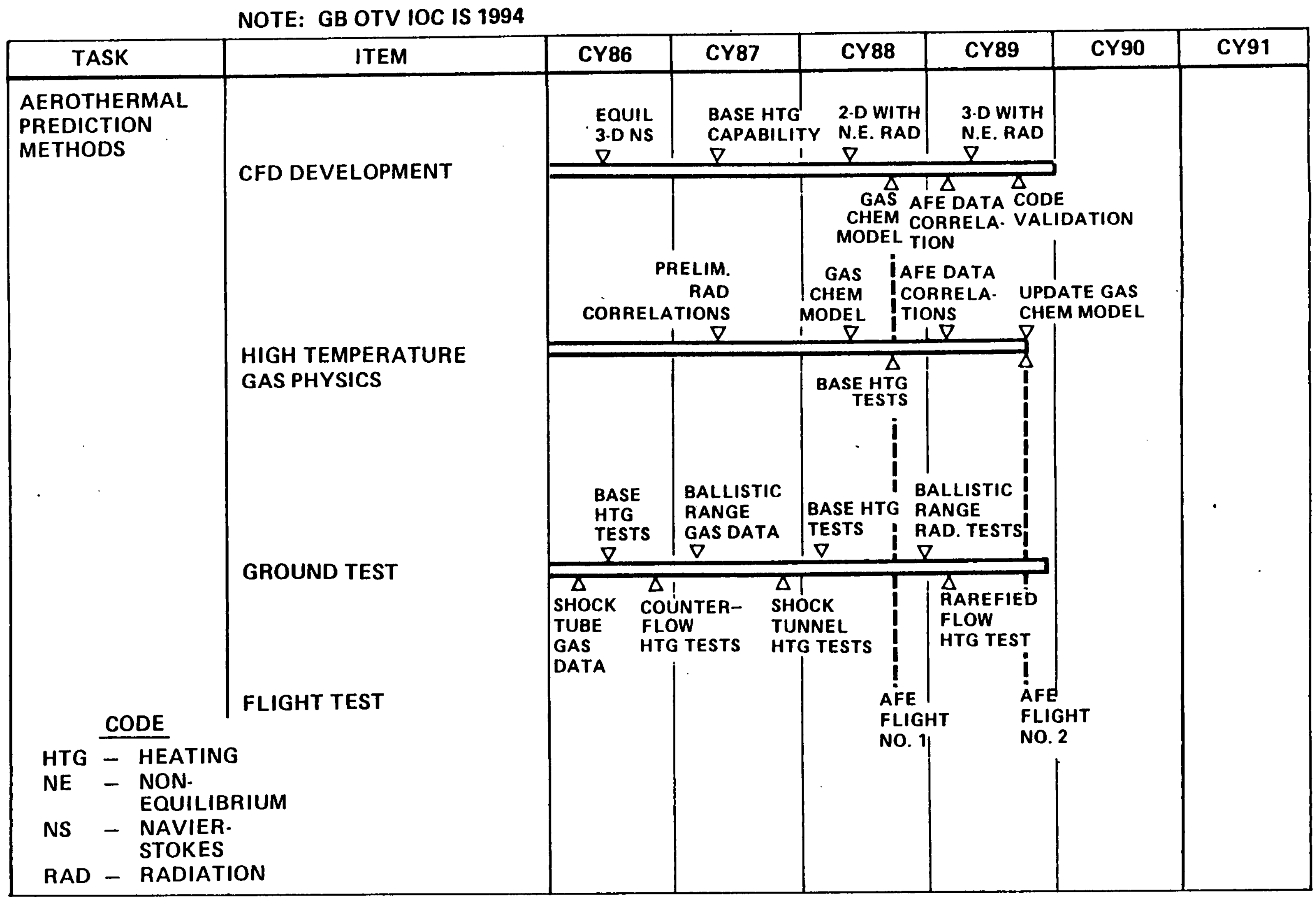

Figure 3.1-1. Aerothermal Schedule

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Table 3.1-2 Aerothermal Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Aerothermal Prediction Methods	• CFD Development	775K	675K	680K	650K	400K	
	• High Temp Gas Physics	515K	515K	485K	485K	300K	
	• Ground Test	530K	730K	530K	430K	430K	
	Total	1,820K	1,920K	1,695K	1,565K	1,130K	

Table 3.2-1. Technology Goals — Thermal Protection

ITEM	TASKS	STATUS	GOALS

FLEXIBLE SURFACE INSULATION	• MATERIAL DEVELOPMENT
	• FABRICATION TECHNIQUES
	• COATINGS
		• SILICON CARBIDE FABRICS WERE TESTED TO 34 BTU/FT^2-SEC
		• CONSTANT THICKNESS TABI AVAILABLE
		• NO FLEXIBLE HIGH TEMP. COATINGS AVAILABLE
			• CAPABILITY FOR 50 BTU/FT^2-SEC
			• VARIABLE THICKNESS BLANKETS
			• FLEXIBLE, HIGH TEMP. COATINGS
			  • NON-CATALYTIC
			  • OPTIMAL OPTICAL PROPERTIES
			  • OXIDATION PREVENTATIVE

	• FSI DESIGN	• SILICON CARBIDE TABI PROMISING, BUT NOT PROVEN
		• TABI/BALLUTE THERMAL TESTS IN AUGUST 1985
			• CAPABILITY TO 50 BTU/FT^2-SEC
			• DESIGN CONCEPT FOR
			  • PACKAGING
			  • ATTACHING

RIGID SURFACE INSULATION	• MATERIAL DEVELOPMENT
	• COATINGS
		• CAPABILITY TO APPROX. 40 BTU/FT^2-SEC
		• CURRENT COATINGS MAY RESTRICT TILE CAPABILITY
			• CAPABILITY TO 70 BTU/FT^2-SEC
			• CAPABILITY TO 70 BTU/FT^2-SEC
			  • NON CATALYTIC
			  • OPTIMAL OPTICAL

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developed by NASA/Ames. This concept features a 3-dimensional, integrally woven structure (no fabric stitching) which provides strength and durability characteristics much superior to previous fabric systems. TABI blankets with silicon carbide fabric external surfaces and cell walls were fabricated, and were thermally tested in August of 1985. This concept appears to have the potential of meeting at least minimum requirements for OTV.

The use of external coatings offer a possible means for reducing surface catalytic properties, tailoring optical properties and inhibiting oxidation. At this time no coatings have been identified that remain flexible at temperatures required for OTV.

Plan. The recommended program consists of parallel efforts to:

(1) Increase the maximum operating temperatures of suitable fabric and felt materials,

(2) improve the design and techniques for fabricating fabric structures, and

(3) develop high temperature FSI coatings with desired optical, catalytic, and oxidation inhibiting properties.

Initially, tasks 1 and 2 would be essentially a continuation of current programs. TABI fabricated using silicon carbide fabrics is currently the most promising candidate for OTV, but the capabilities and limits of this concept must be fully defined.

3.2.2.2 Rigid Surface Insulation

Status. RSI materials currently under development include Alumina Enhanced Thermal Barrier (AETB) at NASA/Ames (ref. 6) and Higher Temperature Performance (HTP) at Lockheed Missiles and Space Co. (ref. 7). Both of these materials appear to maintain dimensional stability to high temperatures better than fibrous refractory composite insulation (FRCI), which are used on the last two Space Shuttle Orbiters.

Currently the RTV bond between the RSI and SIP on the Space Shuttle Orbiters is limited to 550° F. If allowable bondline temperatures could be increased to roughly 650° F RSI minimum RSI thickness would be constrained by the 600° F limit on the graphite/polyimide primary structure, which would result in a reduction in RSI weight of approximately 25 percent.

Plan. Specific tasks for this effort are to:

(1) Identify and develop RSI materials capable of performing at higher temperatures,

(2) develop and validate suitable RSI coatings, and

(3) develop adhesives and processes to permit 650^{o}F RST/SIP bondline temperatures.

3.2.3 Schedule and Resources

The key technology milestones for the thermal protection area are shown in figure 3.2-1. The resources required for the effort are presented in table 3.2-2.

3.3 AERODYNAMICS

3.3.1 Objective

The objective of this effort is to develop the aerodynamic methods and data base for the OTV flight regime. Specific goals are shown in table 3.3-1. The key areas for improvement are; rarefied and non-equilibrium flow effects, improved CFD analysis tools, an expanded empirical data base, aeroelastic loads and stability, and improvements in existing analysis methods. The goals for overall accuracy is $\pm$ 20 percent.

3.3.2 Description

The specific tasks are to develop an experimental data base and resolve technical issues for promising OTV configurations. The experimental data base should simulate as close as possible mach number, enthalpy, and chemical properties of the OTV flight regime. The data should include basic aerodynamic performance and geometry/control parametrics. The analytical data should include benchmark flowfield analyses (e.g., Navier-Stokes, Viscous Shock Layer) of various classes of configuration. These codes should be developed to include viscous interaction and equilibrium techniques.

The flow field prediction methods which are proposed as an output from aerothermal methods effort are also expected to satisfy the requirement for improved aerodynamics flow field methods. Engineering methods should be developed based on correlation of experimental data and computational studies. These methods should be validated with flight test data correlations, such as STS flights (reference "Shuttle Performance- Lessons Learned").

NOTE: GB OTV IOC IS 1994

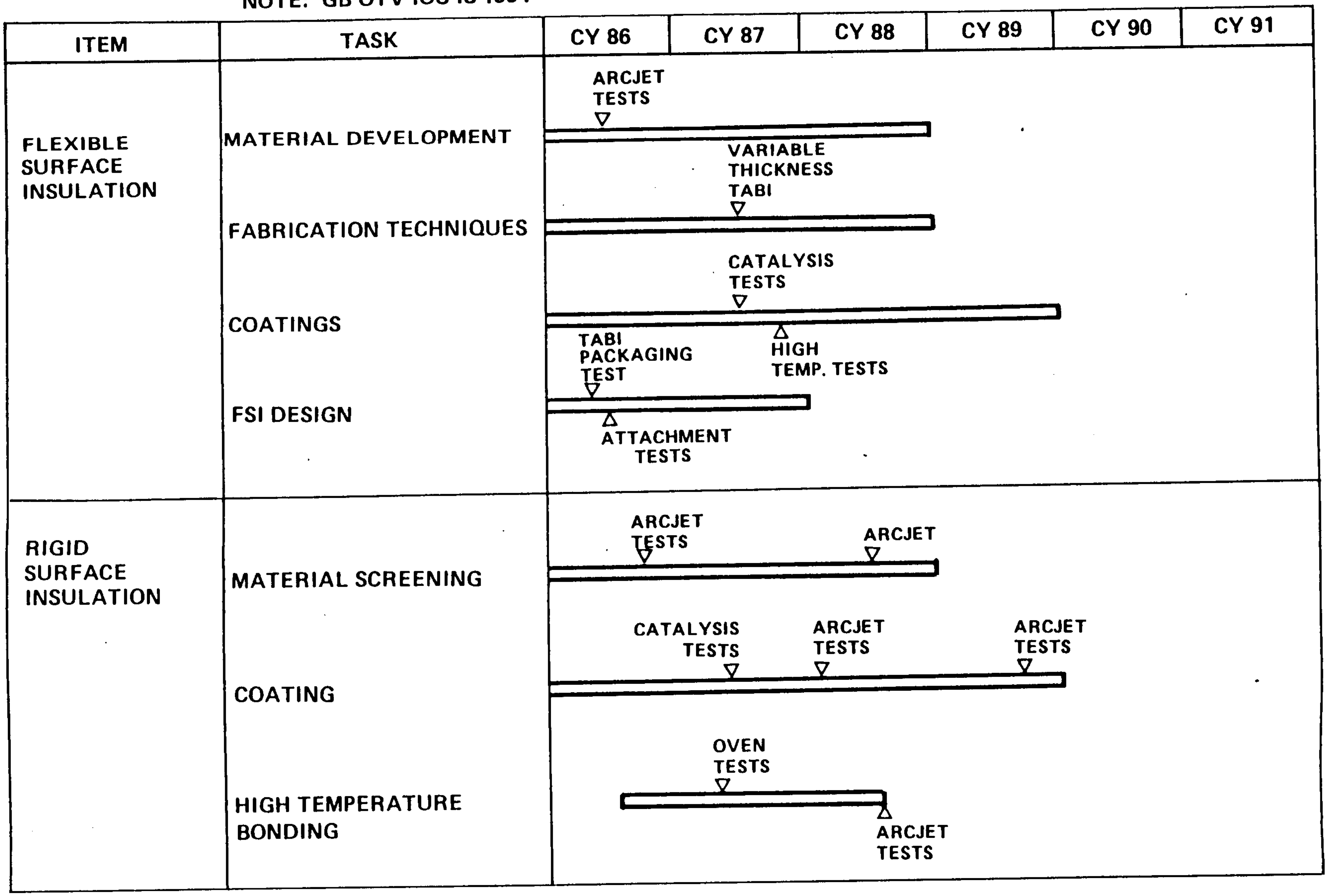

Figure 3.2-1. Thermal Protection Schedule

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Table 3.2-2 Thermal Protection Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Flexible Surface Insulation	• Material screening	100K	100K	50K			
	• Fabrication techniques	200K	200K	150K			
	• Coatings	70K	70K	70K	70K		
	• FSI validation	335K	335K	385K	505K		
Rigid Surface Insulation	• Material development	320K	320K	320K	320K		
	• Coatings	70K	70K	70K	70K		
	• High temp bonding	100K	100K	100K			
	Total	1,195K	1,195K	1,145K	965K		

Table 3.3-1. *Technology Goals — Aerodynamics*

ITEM	TASKS	STATUS	GOALS
FLEXIBLE STRUCTURES	• FLEXIBLE BALLUTE DYNAMICS	• INITIATED UNDER AEROASSIST FLIGHT EXPERIMENT	• VERIFY THAT LIGHTWEIGHT FLEXIBLE STRUCTURE CAN BE USED FOR THE OTV MISSION
	• BALLUTE AERO/ ELASTIC	• NO AERO/ELASTIC TEST DATA AVAILABLE	• PROOF OF CONCEPT FOR INSULATED BALLUTE WITH DRAG MODULATION
AERO PREDICTIONS	• AERO METHODS DEVELOPMENT	• METHODS AVAILABLE FOR CONTINUUM FLOW WITH CORRELATION FACTORS FOR RAREFIED FLOWS	• IMPROVE ACCURACY FOR CURRENT METHODS, DEVELOP METHODS FOR NON-EQUILIBRIUM FLOW, RAREFIED FLOWS, AND VALIDATE METHODS WITH FLIGHT TEST DATA
	• OTV AERODYNAMIC FORCE AND CONTROLS TEST	• DATA AVAILABLE FOR FOR CONTINUUM FLOW CONDITIONS	• EXTEND DATA BASE TO MATCH RAREFIED FLOW FLIGHT REGIME MORE CLOSELY

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Critical issues for promising configurations need to be resolved through analysis and test. Currently flutter analysis of the ballute configuration is proposed with follow-up tests as required. Flowfield techniques also need to be developed for analyzing jet counter flow concepts for modulating drag.

3.3.3 Schedule and Resources

The key technology milestones for the aerodynamics area are shown in figure 3.3-1. The resources required for the effort are presented in table 3.3-2.

3.4 PROPULSION

3.4.1 Objectives

Currently funded technology programs established the goals shown in table 3.4-1 based on earlier OTV studies with engine thrust requirements of approximately 15,000 lbf. The amended goals shown by the figure are recommended to be consistent with the 5000 lbf thrust level and 1,000:1 nozzle expansion ratio found optimum by this OTV study now nearing completion.

3.4.2 Description

The recommended program for providing a new OTV engine is an extension of the current programs with Aerojet, Pratt & Whitney and Rocketdyne. The goals, as shown in table 3.4-1, are driven by the OTV needs, and the programs are structured to provide the technology to enable a low risk and minimum cost DDT&E (design, development, test and engineering) program for an advanced engine to proceed in the early 1990's.

For the thrust chamber the chief concerns are long life and increased energy extraction. Advanced materials and enhanced heat transfer concepts have been identified. For the nozzle, extension and retraction mechanisms, performance and fabrication of very high area ratio lightweight nozzles are the technology issues.

In the turbomachinery components, high rotation speeds raise life and performance concerns for the bearings, seals and gears as well as concerns over material stress levels and fabrication.

In instrumentation and controls, the need for flexible, adaptive controls is evident, as well as health monitoring capability. The SSME incorporates rudimentary levels of the control and health monitoring but the OTV will require considerably more because of its multiple restart requirements. In addition, space basing the OTV is also a possibility

NOTE: IOC FOR GB OTV IS 1994; SB IS 1997

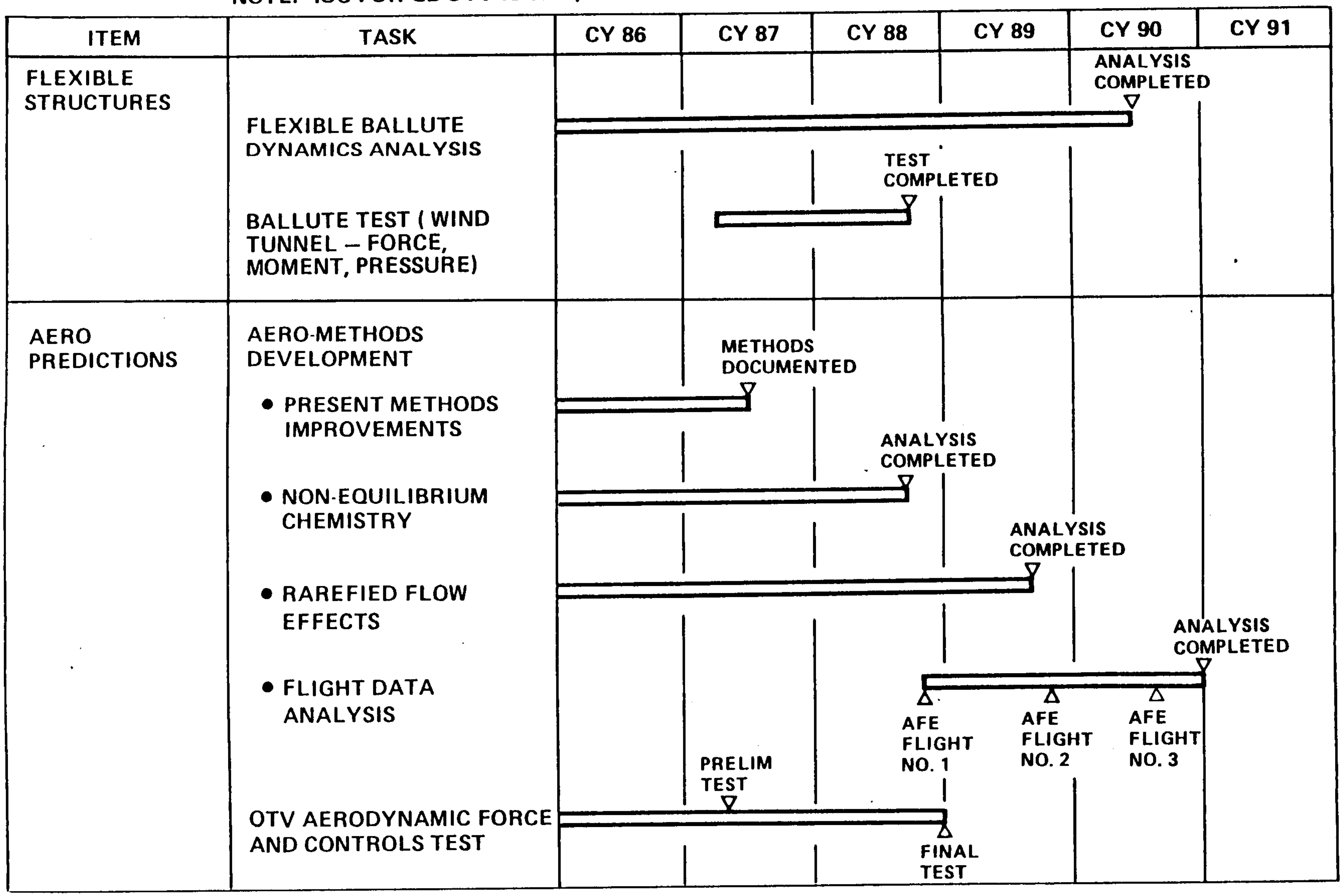

Figure 3.3-1. Aerodynamics Schedule

OTV-1012

Table 3.3-2 Aerodynamics Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Flexible Structures	• Flexible ballute dynamics	400K	400K	400K	400K	400K	
	• Ballute test		100K	300K			
Aero-Predictions	• Aero methods development	200K	200K	200K	150K	100K	
	• OTV aerodynamic force and controls test	100K	100K	200K			
	Total	700K	800K	1,100K	550K	500K	

Table 3.4-1. *Technology Goals — Propulsion*

ITEM	TASKS	STATUS	GOALS: CHARACTERISTIC	PRIOR NASA ESTABLISHED GOAL	AMEND. GOAL
ADVANCED CRYOGENIC ENGINE	• COMPONENT DEVELOPMENT • COMBUSTERS • TURBOMACHINERY • INSTRUMENTATION • CONTROLS	• NASA FUNDED CONTRACTS • PRATT & WHITNEY • AEROJET • ROCKETDYNE	• THRUST, LBF	15,000	5,000
	• RESEARCH ENGINE		• AREA RATIO	—	1000:1
	• ENGINE MOCKUP		• VACUUM SPECIFIC IMPULSE, LBF-SEC/LBM	520 30:1	490 30:1
			• VACUUM THRUST THROTTLE RATIO	30:1	30:1
			• NET POSITIVE SUCTION HEAD, FT-LBF/LBM		
			• HYDROGEN	0	0
			• OXYGEN	0	0
			• WEIGHT, LBM	360	200
			• LENGTH (STOWED), IN.	40	40
			• SERVICE LIFE		
			• BETWEEN OVERHAULS, CYCLES/HOURS	500/20	500/20
			• SERVICE FREE, CYCLES/HOURS	100/4	100/4

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and will increase the difficulty of performing inspections. As such health monitoring would play a major role in maintainability.

It is envisioned that subcomponent and component technologies will be validated in research engines to uncover any system related problems. Recent OTV studies of the thrust level and engine number issues have concluded that an engine thrust level of 5000 lbf is most appropriate. The research engines should be approximately at this thrust level.

3.4.3 Schedules and Resources

The key technology milestones for the propulsion area are shown in figure 3.4-1. The resources reqwuired for the effort are presented in table 3.4-2.

3.5 CRYOGENIC FLUID MANAGEMENT

3.5.1 Objectives

The recommended cryogenic fluid management technology program addresses the problems and uncertainties associated with acquisition, storage, transfer, and gaging cryogenic liquids in the low-g (less than 10^{-5}g) environment experienced both at the Space Station and at the OTV during coast periods. Goals of the recommended program shown in table 3.5-1 are: minimum propellant boil-off losses, efficienct propellant acquisition and transfer, and accurate propellant gaging.

3.5.2 Description

The Cryogenic Fluid Management Facility (CFMF) Experiment is the only currently funded experiment that will permit a resolution of the bulk of the low-g fluid management questions. Most of the MLI, MLI/Foam, VCS, and structural support thermal control requirements can be determined in a 1-g environment and have been studied extensively. Table 3.5-2 lists the technology areas that CFMF will address. Unfortunately, with the planned CFMF launch date, the questions answered by CFMF will not be available for the initial OTV. However, since the initial OTV will be ground-based and all of the critical questions requiring resolution pertain to low-g operations, work around techniques can be used (albeit at the expense of added propellant for additional settling maneuvers) until the spacebased OTV is required. The spacebased OTV and an on-orbit propellant storage facility (probably at or near the station) will require low-g gaging, acquisition, and transfer capability. The IOC of the SBOTV and the on-orbit propellant storage facility will allow the results from CFMF should

NOTE: IOC FOR GB OTV IS 1994; SB OTV IS 1997

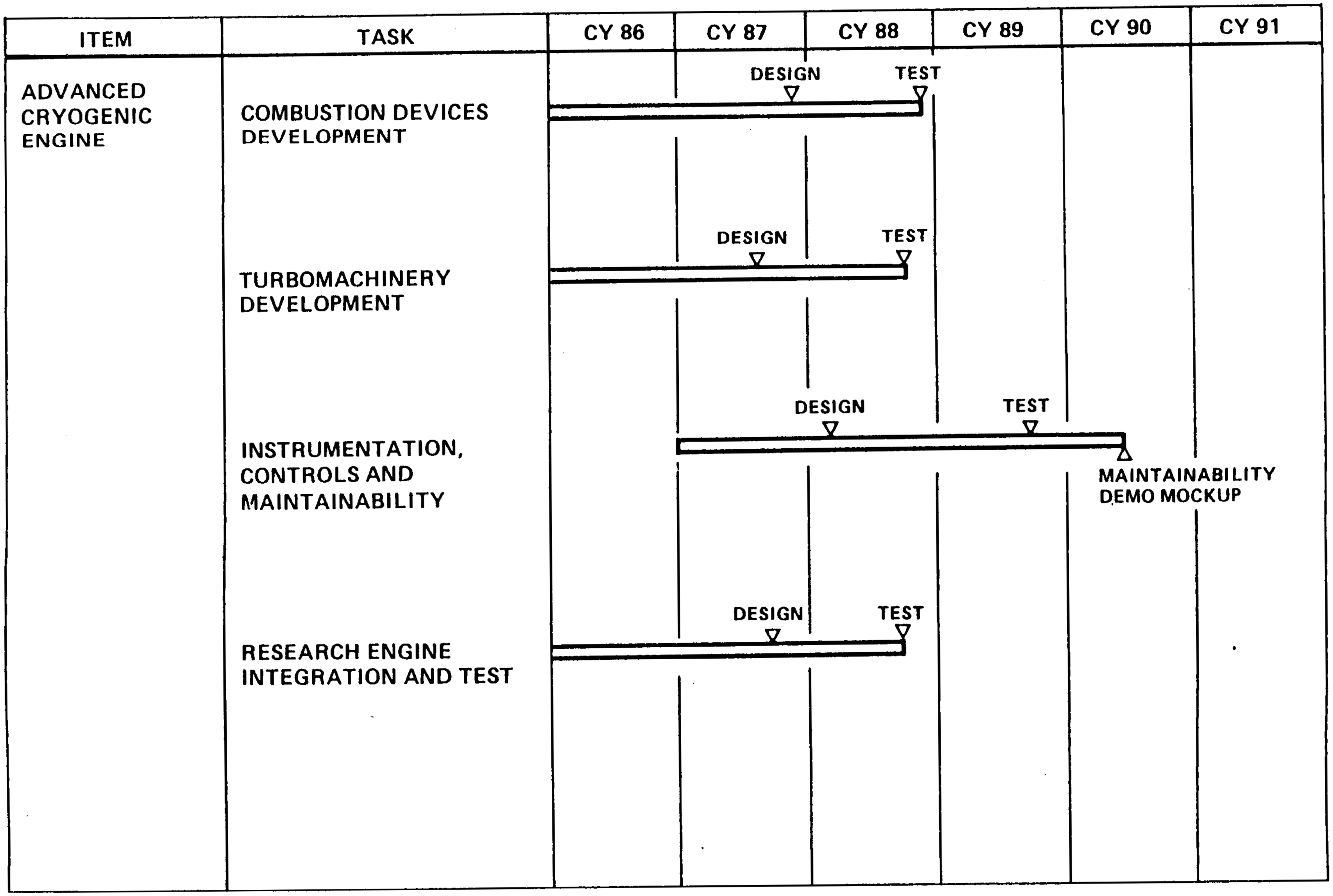

Figure 3.4-1. Propulsion Schedule

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Table 3.4-2 Propulsion Resource Requirements

Item	Task	Cost (1985 Dollars) FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Advanced Cryogenic Engine	• Combustion devices development	2,500K	4,850K	3,300K	2,050K	2,000K	1,700K
	• Turbomachinery development	2,850K	5,250K	4,600K	2,000K	2,050K	1,750K
	• Instrumentation, controls and maintainability	700K	2,400K	3,800K	3,250K	2,450K	2,000K
	• Research engine integration and test	1,000K	1,200K	3,600K	5,900K	4,050K	2,100K
	• Propellant	300K	400K	1,700K	1,800K	1,050K	550K
	Total	7,400K	14,100K	17,000K	15,000K	11,600K	8,100K

Table 3.5-1. Technology Goals – Cryogenic Fluid Management

TASKS	STATUS	GOALS
LOW "G" FLUID ACQUISITION AND TRANSFER	• LOW "G" ACQUISITION AND TRANSFER OF STORABLE PROPELLANTS IS STATE-OF-THE-ART	• LOAD TO LESS THAN 5% ULLAGE
	• CRYOGENIC LOW "G" ACQUISITION AND TRANSFER HAS NOT BEEN DEMONSTRATED	• EXPULSION EFFICIENCY GREATER THAN 97%
	• CRYOGENIC FLUID MANAGEMENT FACILITY (CFMF) SCHEDULED TO DEMONSTRATE CONCEPT (SEE TABLE 3.5-2)	
VENTING	• A THERMODYNAMIC VENT SYSTEM HAS BEEN DEMONSTRATED ON THE GROUND AND WILL FLY ON CENTAUR G PRIME	• ESTABLISH PERFORMANCE OF THERMODYNAMIC VENT SYSTEMS FOR USE IN STORAGE DEPOT
	• CFMF WILL DEMONSTRATE (T 3.5-2)	• NO LIQUID VENTING
THERMAL CONTROL	• VAPOR COOLED SHIELDS HAVE BEEN USED FOR SMALL TANKS, PERFORMANCE FOR LARGE TANKS WITH INTERMITTENT OUTFLOW IS NEEDED	• LESS THAN 0.02% PER DAY BOILOFF RATES FOR ON-ORBIT STORAGE TANKS
	• MLI FOR SPACE BASED; PURGED MLI OR MLI/FOAM FOR GROUND BASED	• NO GN_2 OR AIR LIQUEFACTION FOR GB OTV
QUANTITY GAGING	• NO PROVEN METHODS FOR LARGE TANKS IN LOW "G"	• ACCURACIES BETTER THAN 1%
	• CFMF WILL EVALUATE (T3.5-2)	• ON-DEMAND GAGING

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Table 3.5-2 LeRCs Cryogenic Fluid Management Facility (CFMF) Experiment Technology Areas

- Receiver Tank Childown
- No-vent Fill of Empty Tank
- Supply Tank Refill
- Receiver Tank Refill
- Tank Pressurization
- Liquid Thermal Conditioning
- Acquisition Device Performance
- Transfer Line Chilldown
- Liquid Settling and Outflow
- Helium Pressurant Venting
- Liquid Flow Measurement
- Multi-Layer Insulation (MLI)
- Thermodynamic Vent System (TVS)
- Liquid Quantity Gaging
- Pressurization and Thermal Code Verification

contribute to these designs. As a caveat to the above, the use of a tethered propellant depot may ameliorate the gaging and transfer problems at the station.

Subsequent to the preparation of this report, events have occurred that have changed the relative schedules of the CFMF, OTV, HLV, and Space Station programs. As of June 1987, the following facts would influence the foregoing technology plan:

CFMF. The Challenger accident and subsequent banning of LH_2 from the Orbiter payload bay has led CFMF being launched from a Delta booster for a 2-year mission as a free-flyer in 1994.

OTV. The first GBOTV flight is scheduled for mid-1996 according to a presentation made by Don Perkinson of MSFC on 28 April 1987 at LeRC. This vehicle cannot benefit from CFMF findings. The earliest SBOTV, then, is circa 2000 and may benefit from CFMF.

Space Station. The Space Station IOC is currently 1996. Costs have increased and capability has diminished to compensate. Upgrading to support a SBOTV will be no sooner than FY 2000.

Heavy Launch Vehicle. Since LH_2 is no longer allowed in the Orbiter payload bay, the OTV must be of the ACC type or delivered by an HLV. An Air Force HLV program (the ALS) is just getting started and may or may not be the best vehicle for OTV launches.

3.5.3 Schedule and Resources

The key technology milestones for the cryogenic fluid management area are shown in figure 3.5-1. The resources required for the effort are presented in table 3.5-3.

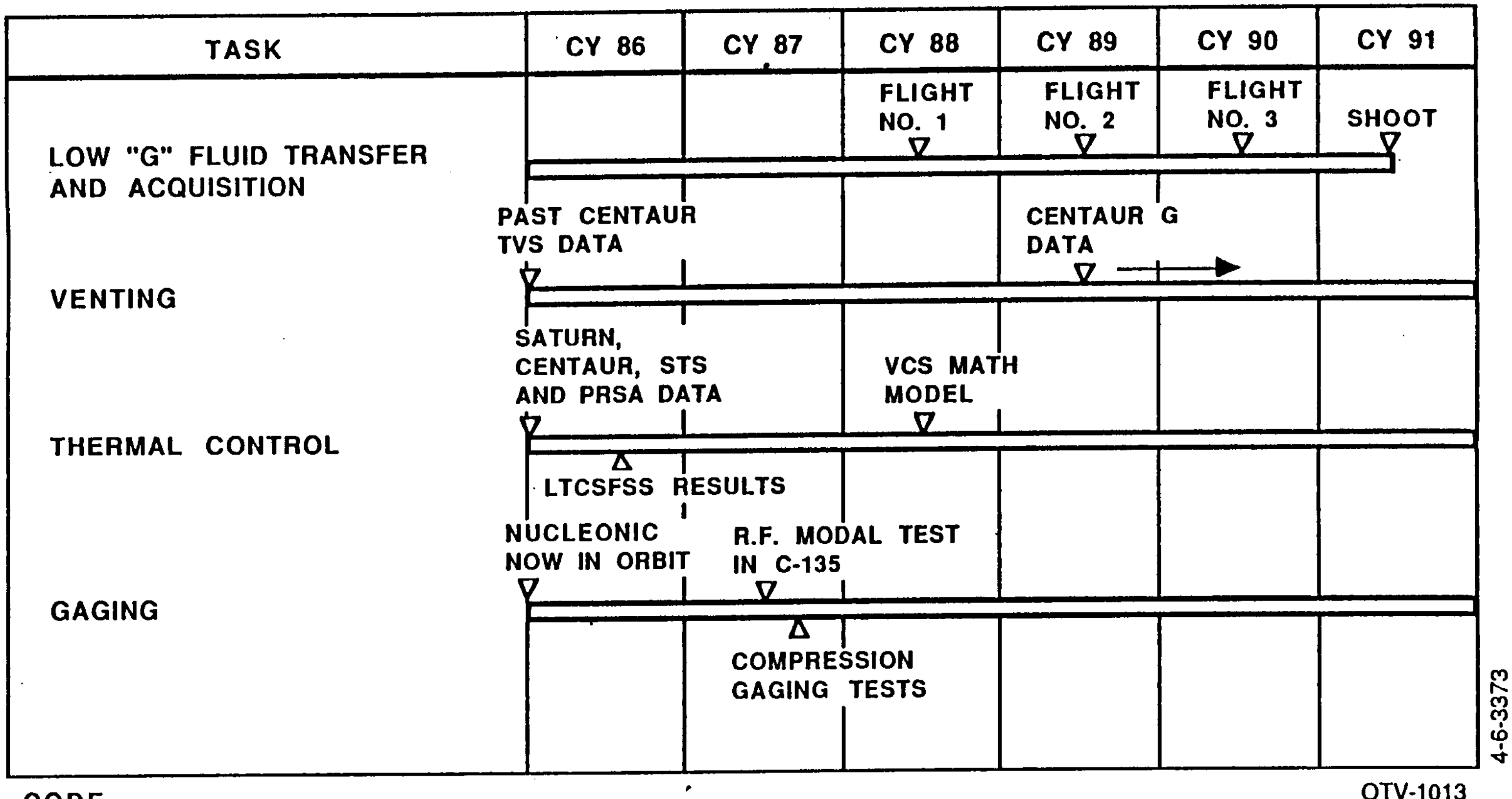
3.6 CRYOGENIC TANKAGE

3.6.1 Objectives

The primary objective of this effort is to assess potential implications of propellant tankage explosive rupture and establish guidelines, methodologies and supporting data to support development of applicable design criteria and companion design concepts within acceptable weight limits.

At the time this analysis was done, data on aluminum lithium alloy at cryogenic temperatures were not available. Data available as of June 1987 shows that weight reduction for cryogenic tanks can be achieved, however, large scale welding still must be demonstrated.

NOTE: ASSUMED IOC FOR GB OTV IS 1994; SB OTV IS 1997



CODE

TVS = THERMODYNAMIC VENT SYSTEM

VCS = VAPOR COOLED SHIELD

LTCSFSS = LONG-TERM CRYO STORAGE FACILITY SYSTEMS STUDY

SHOOT = SUPER HELIUM ON-ORBIT TRANSFER EXPERIMENT

PRSA = POWER REACTANT STORAGE ASSEMBLY

Figure 3.5-1. Cryogenic Fluid Management Schedule

Table 3.5-3 Cryogenic Fluid Management Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Low "g" cryogenic fluid management	• Low "g" fluid transfer	5M	6M	8M	10M	5M	3M
	• Venting						
	• Thermal control	0.2M	0.3M				
	Total	5.2M	6.3M	8.0M	10.0M	5.0M	3.0M

3.6.2 Description

The specific tasks, status, and goals for cryogenic tankage are summarized in table 3.6-1. The most significant problem is the prevention of and response to tank penetration by meteoroids or debris on-orbit.

3.6.2.1 Consequences of Explosive Rupture

Status. No applicable data is known to exist, other than basic physical properties.

Data is currently being developed for the Space Station program but is not available at this time.

Plan. A literature survey should be conducted to obtain whatever applicable data may exist. Resultant data plus physical properties and available OTV tankage concepts should be employed to generate the following data and/or assessments:

(1) Energy release for LOX and LH_2 tanks as functions of: tank capacity, pressure prior to rupture and percent full.

(2) Tank pressure rise due to penetration of debris particles of various sizes and velocities.

(3) Vehicle/payload responses to applicable tank explosive ruptures.

(4) Consequences to Space Station resulting from OTV propellant tank explosive rupture as a function of proximity.

3.6.2.2 Explosive Rupture Mechanics

Status. Applicable 2219 aluminum fracture mechanics data at liquid nitrogen temperature is available. Limited particle impact data and computer codes for predicting/quantifying damage characteristics are available. There is no known source of information relating explosive rupture parametric boundaries in terms of particle and tank/protection system characteristics.

Plan. A literature survey should be conducted to obtain available applicable data. Explosive rupture parametric boundaries should be established for a broad range of particle and tank/protection system characteristics.

3.6.2.3 Penetration Analysis Update

Status. Meteoroid/space debris penetration analysis tools are currently available, and in the process of being updated, for predicting the probability of penetrating a uniform spherical shell by particles impacting at right angles to the shell. Methodologies for assessing non-spherical, non-uniform tankage/protection shells and non-right angle impacts are not available at this time.

Table 3.6-1. Technology Goals — Cryogenic Tankage

TECHNOLOGY	TASK	STATUS	GOALS
PROPELLANT TANKAGE EXPLOSIVE RUPTURE PREVENTION	• ASSESS CONSEQUENCES OF EXPLOSIVE RUPTURE	• HAS NOT BEEN ADDRESSED	• QUANTIFY ENERGY RELEASE • ASSESSMENTS OF FRAGMENT SIZES AND TRAJECTORIES • ASSESSMENT OF HAZARD TO SPACE STATION
	• DEVELOP EXPLOSIVE RUPTURE MECHANICS	• ANALYTICAL TOOLS AVAILABLE • PREDICTIONS HAVEN'T BEEN MADE	• ESTABLISH TANKAGE DESIGN AND PARTICLE PARAMETRIC BOUNDARIES.
	• PENETRATION ANALYSIS UPDATE	• CURRENT ANALYSIS RECOGNIZE ONLY UNIFORM SPHERES AND RIGHT ANGLE IMPACTS	• ABILITY TO PREDICT PENETRATION PROBABILITIES FOR COMPLEX DESIGN SHAPES
	• DESIGN TO AVOID EXPLOSIVE RUPTURE	• KNOWN TECHNIQUES FOR AVOIDING EXPLOSIVE RUPTURE INCREASE TANK WEIGHT AND/OR PROBABILITY OF PENETRATION	• DEVELOP METHODOLOGY FOR MINIMUM WEIGHT IMPACT COMPATIBLE WITH NO PENETRATION REQUIREMENTS
	• DESIGN CRITERIA	• CURRENTLY DOES NOT ADDRESS METEOROID/DEBRIS	• COMPATIBLE TANKAGE/ PROTECTION DESIGN CRITERIA
	• PROPELLANT TANK MATERIAL REPLACEMENT	• WELDED 2219 ALUMINUM IS CURRENTLY STANDARD	• UPDATED MATERIALS ASSESSMENTS

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Plan. A survey should be conducted to identify and obtain the most complete methodologies available. Those methodologies should then be extended to reflect applicable non-uniformities and impact angular distributions to permit improved predictions of penetration and explosive rupture for realistic vehicle and tankage designs.

3.6.2.4 Design To Avoid Explosive Rupture

Status. Known techniques for avoiding explosive rupture include: (1) design the pressure vessel to operate at low stress to provide a large critical crack length; (2) use light weight or no shield; and (3) use small shield to pressure vessel standoff distance. Very low operating stresses are impractical from a weight standpoint and use of light weight shields with a small standoff distance is counterproductive in terms of reducing probability of penetration.

Plan. Develop parametric design guidelines for avoiding explosive rupture or reducing probability of explosive rupture to a known finite value while maintaining probability of no penetration to a desired level.

3.6.2.6 Updated Materials Assessments and Recommendations

Status. Available data indicates that better strength to weight ratios through the use of lithium aluminum or metal matrix composites for the tank construction are possible. Information on these new weldable alloys is limited and indicates that additional development work is required for their use. Portions of that work are in progress.

Plan. Determine the parameters which are the design drivers for the tankage/protection system for the selected OTV. Obtain corresponding parameter values or estimates for candidate materials. Develop tankage designs for the selected OTV to sufficient depth to obtain reasonable weight impact assessments. Determine vehicle potential performance/cost impact. Assess development costs remaining to advance the technology to the level required for OTV tankage. Make development funding support recommendations for applicable materials.

3.6.3 Schedule and Resources

The key technology milestones for the cryogenic tankage area are shown in figure 3.6-1. The resources required for the effort are presented in table 3.6-2.

NOTE: GB OTV IOC IS 1994

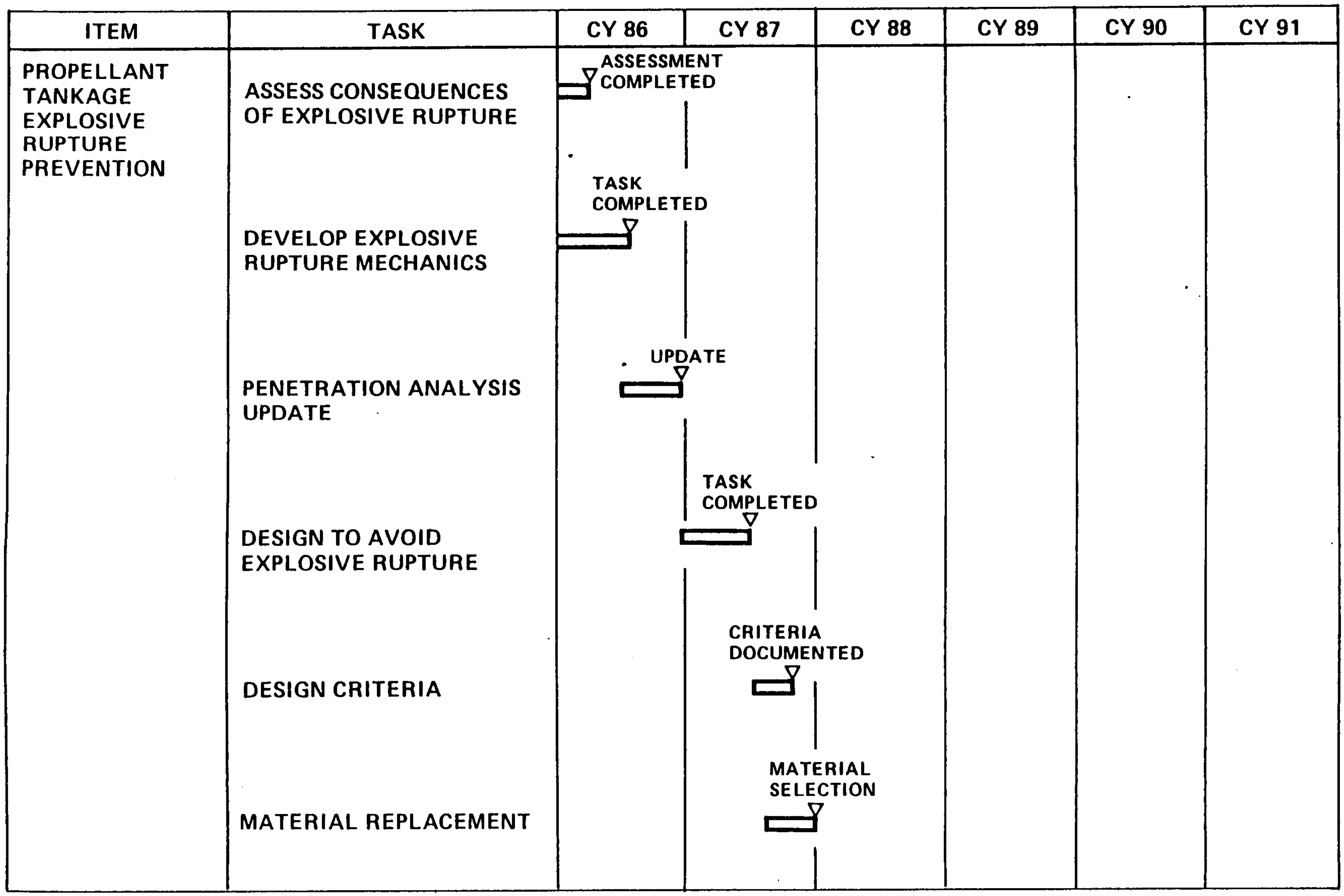

Figure 3.6-1. Cryogenic Tankage Schedule

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Table 3.6-2 Cryogenic Tankage Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Propellant Tankage Explosive Rupture Prevention	• Assess consequences of explosive rupture	50					
	• Develop explosive rupture mechanics	120K					
	• Penetration analysis update	120K					
	• Design to avoid explosive rupture		90K				
	• Design Criteria		30K				
	• Material replacement		90K				
	Total	290K	210K				

3.7 GUIDANCE, NAVIGATION AND CONTROL

3.7.1 Objective

The objective of the guidance task is to identify an optimal adaptive guidance scheme which has the capability to use atmospheric prediction, to adaptively shape the trajectory to satisfy the thermal constraints, and to satisfy the required mission orbital constraints at atmospheric exit.

3.7.2 Description

Status. The OTV mission has a set of guidance problems which include propulsive orbit transfers, rendezvous, and aeroassist maneuvers. Each of these problems can be considered independently and treated using existing guidance algorithms. The state-of-the-art for propulsive orbit transfers is Inertial Upper Stage (IUS). The IUS uses a strap-down, redundant, inertial navigation system. An explicit adaptive guidance algorithm (Gamma Guidance) commands the orbit transfer using thrust vector control and a reaction control system (RCS).

The state-of-the-art for reentry guidance, navigation and control systems is the Space Shuttle system. The Space Shuttle uses onboard precision accelerometers and gyros for navigation and the reaction control system thrusters to vary the bank angle and angle of attack for lift vector control during reentry. The guidance system uses a series of five reference drag profiles to determine angle of attack and bank angle commands through the region of high aerodynamic heating, equilibrium glide, constant drag and the final transition phase.

Data from STS flights indicate that there are atmospheric dispersions that are not predicted by existing atmospheric models. Guidance using drag modulation requires an accurate understanding of the lower portion of the thermosphere (250Kft-400Kft). Density dispersions are one of the largest contributors to guidance and control error. Better knowledge of the atmosphere will mean expanded mission capability and fewer design restrictions.

The primary guidance effort for OTV is concentrated on the aeroassist guidance requirements. The NASA Centers currently have development efforts underway to investigate guidance algorithms for OTV applications. These efforts include adaptations of the Apollo and Space Shuttle guidance algorithms and application of explicit adaptive guidance to the OTV problem. In addition to the application of these algorithms to the various OTV vehicles, these studies are also addressing the impact of various error sources on the guidance algorithm and the required control capability of the vehicle. The uncertainty in the knowledge of the atmosphere is a critical parameter in the analysis of the guidance system requirements.

Plan. The recommended program consists of six tasks as shown in table 3.7-1.

The objective of the guidance task is to identify an optimal adaptive guidance scheme which has the capability to use atmospheric prediction, to adaptively shape the trajectory to satisfy the thermal constraints, and to satisfy the required mission orbital constraints at atmospheric exit.

The investigation should include a range of systems from adaptation of shuttle guidance algorithms to direct, explicit, optimal algorithms. The different algorithms should be compared to determine the relative performance benefits, flexibility with respect to various missions, and adaptability to changing vehicles. The guidance schemes should be tested against realistically severe atmospheric dispersions to determine the control limits required to maintain the vehicle within thermal constraints.

In addition to the aeroassist guidance work, there should be an effort to study guidance algorithms and requirements for autonomous rendezvous capability. For the OTV vehicle this will have application to retrieving an existing satellite, as well as to docking with a shuttle or the space station after the aeroassist maneuver.

3.7.3 Schedule and Resources

The key technology milestones for the aerothermal area are shown in figure 3.7-1. The resources required for the effort are presented in table 3.7-2.

3.8 ATMOSPHERIC PHYSICS

3.8.1 Objective

The overall objective is to minimize uncertainties with regard to the atmospheric density that will be encountered during an OTV aeropass maneuver. Of particular interest are altitudes from about 240,000 ft to 280,000 ft at low latitudes.

3.8.2 Description

Status. State of the art in an atmospheric model for all altitudes is characterized by the Global Reference Atmosphere Model, (GRAM), developed under sponsorship of O.E. Smith at NASA/MSFC. GRAM uses semiempirical equations to relate density at

Table 3.7-1. *Technology Goals — Guidance, Navigation, and Control*

ITEM	TASKS	STATUS	GOALS
ADAPTIVE GUIDANCE	• IDENTIFY OPTIMAL ADAPTIVE GUIDANCE ALGORITHM APPLICABLE TO ALL OTV MISSION REQUIREMENTS • DEVELOP UNIFIED GUIDANCE STRUCTURE • SIMULATE AND TEST	• CANDIDATE ALGORITHM IDENTIFIED (GAMMA GUIDANCE FROM IUS) • CONCEPT HAS BEEN APPLIED TO OTV AEROMANEUVER	• INCREASE RELIABILITY AND ADAPTABILITY TO OFF NOMINAL CONDITIONS • SIMPLIFY MISSION PLANNING • REDUCE PREMISSION COMPUTATIONAL EFFORT (REDUCED COST OF MDL)
ALGORITHM SELECTION	• SIMULATE OTV MISSION USING EXISTING ALGORITHMS (SPECIALIZED FOR EACH PHASE OF THE MISSION) • COMPARE RESULTS BETWEEN SPECIALIZED ALGORITHMS AND UNIFIED ADAPTIVE ALGORITHM	• COMPARISONS FOR AERO-MANEUVER PHASE OF OTV EXIST	• DETERMINE MOST COST EFFECTIVE GUIDANCE CONCEPT FOR OTV
RENDEZVOUS	• IDENTIFY AN EFFECTIVE ALGORITHM FOR AUTONOMOUS RENDEZVOUS CAPABILITY	• GROUND PREPLANNED	• DEVELOP AUTONOMOUS RENDEZVOUS CAPABILITY TO ENHANCE THE FLEXIBILITY AND RELIABILITY OF THE OTV

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NOTE: IOC FOR GB OTV IS 1994; SB OTV IS 1997

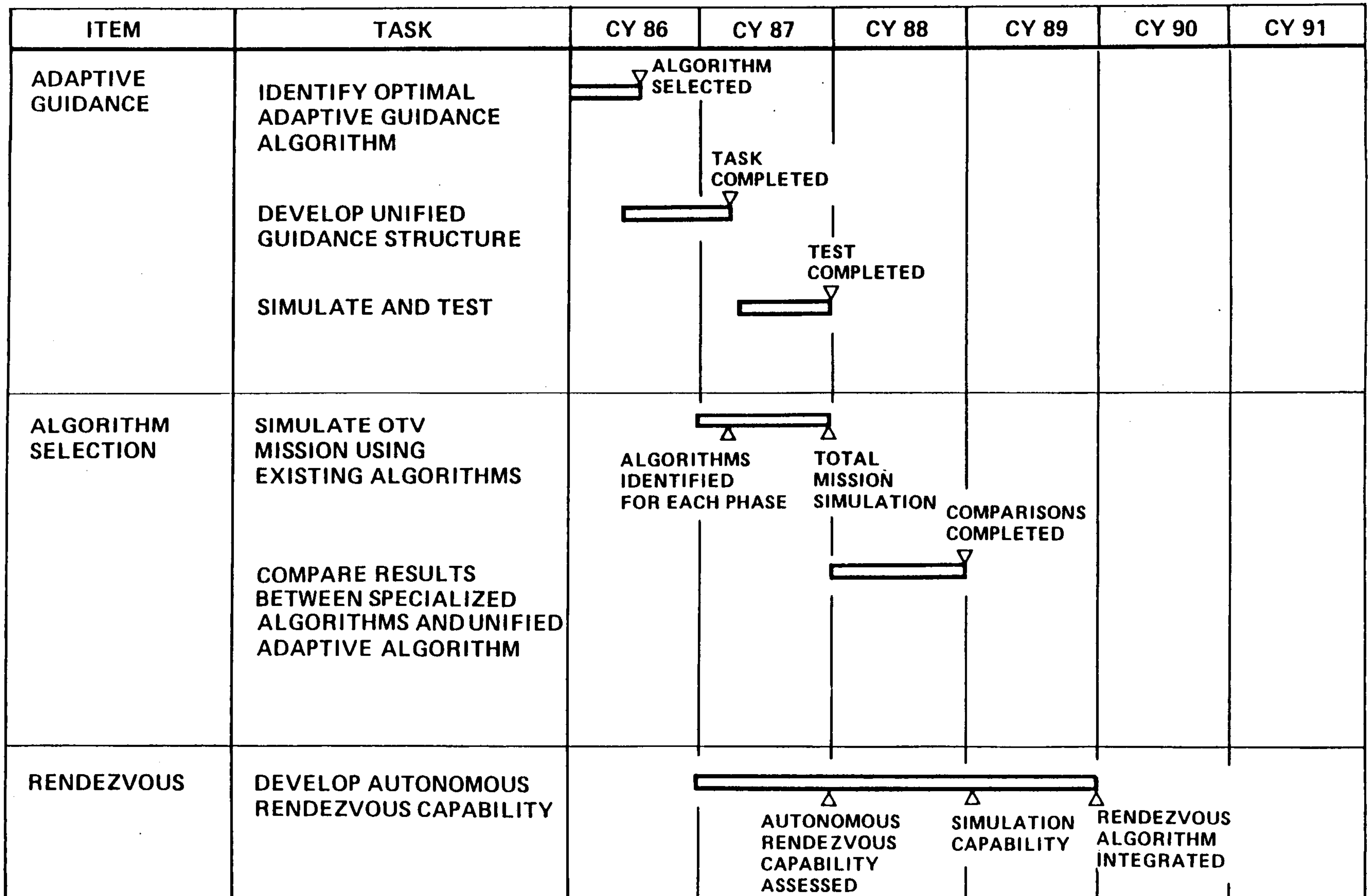

Figure 3.7-1. Guidance, Navigation, and Control Schedule

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Table 3.7-2 Guidance, Navigation, and Control Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
Adaptive Guidance	• Identify optimal adaptive guidance algorithm	150K					
	• Develop unified guidance structure	150K	50K				
	• Simulate and test		150K				
Algorithm Selection	• Simulate OTV mission using existing algorithms		100K				
	• Compare results between specialized algorithms and unified adaptive algorithm		300K	400K			
Rendezvous	• Develop autonomous rendezvous capability		100K	400K	400K		
	Total	300K	700K	800K	400K		

various altitudes to latitude, season, time of day, and solar activity. GRAM-MOD 3 includes wind models, as well as, a statistical model which predicts the large scale density variations (tides and planetary waves) and small scale variations (turbulence and gravity waves). The data base of perturbation magnitudes and magnitude profiles is designed to insure compliance with the perfect gas law and the hydrostatic equation. The data between 90 and 115 kilometers is generated by a fairing technique between the Jacchia and Groves models to produce a smooth transition from one model to the other. The smoothing is achieved at the cost of accuracy. For OTV a consistent model from 75- 120 kilometers would be highly desirable. A limitation of GRAM is that the southern hemisphere is modeled as a six month displacement of the northern hemisphere.

The most recent U.S. Standard Atmosphere is from 1976. Like the GRAM the U.S. STD 76 does cover the entire range of interest; however it does not model as many of the predictable atmospheric variables. This model is also known to have deficiencies in particular in the region above 70 km which includes the region of interest for OTV.

The Air Force 1978 model is more recent than the standard model. However, it is limited to 90 km which is below the limit of the effective atmosphere for OTV, and it does not model as many variables as GRAM.

Although the CIRA, COSPAR International Reference Atmosphere, 1972 does not offer anything more than the other models, it is being revised, and the revisions represent a significant improvement to the model. The revision is taking place in two phases. The first phase, to be released in late 1985, covers the 18-80 kilometer range. The second phase, to be released in late 1986 or early 1987, covers the 80-120 kilometer range. The revisions will take advantage of new data, add longitudinal variation, and include separate models of the northern and southern hemispheres. This is a data base update and it does not include the addition of a statistical model.

The data used in developing the above models was gathered prior to the mid-seventies. There is more data available now that could be useful in upgrading the models. Both the GRAM and STD 76 documents say that the data was most sparse in the 50-100 km range, the region of particular interest for OTV.

The STS data is in the altitude of interest, but it is at a higher latitude. Although there have not been very many flights, the data that is available provides a very detailed, realistic picture of what a typical atmospheric profile would be like. The limited number of flights will make a statistical analysis difficult.

Data from lidar experiments will be valuable for OTV because time and spatial correlations can be derived from this data. There have been a series of experiments in the 30-100 km range at middle latitudes. For the mentioned experiments the altitude resolution was only 3.6 km. More recently it has been predicted that by using a high power laser and a large diameter telescope, the altitude resolution could be increased to as much as 15m.

Some of the most abundant currently available data comes from the Robin spheres. There are at least five years worth of data on tape waiting to be processed. One of the objections to using this data is that much of it lies outside the latitudes of interest. This is true, but there are at least two stations within the area of interest, Kwajalein at 8° 44' N and Ascension Island at 7° 59' S. Another objection is that the Robin data does not show much wave structure above 70 kilometers. The claim is true but that does not mean that useful information cannot be gained from the analysis. It is also worth noting that there is sufficient data for statistical analysis.

In a different category from the above mentioned models, a computer program has been written at CSDL to model atmospheric density disturbances due to gravity waves, Kelvin-Helmholtz instabilities, and Bolgiano layers. The program is completely deterministic. All required parameters of the atmospheric perturbations must be specified explicitly by the user. This program can give insight into what distrubances to expect and how to interpret data.

Plan. The recommended atmospheric physics technology program is shown in table 3.8-1. We propose that the first program be funded immediately. The goal of this program is to produce a high fidelity model of the thermosphere at low latitudes that includes mean profiles and realistic random perturbations. It is expected that this can be accomplished within the framework of an existing model. The first phase of the program of analyzing the existing data to produce a better picture of the atmospheric density in the OTV region of interest can be started immediately and produce useful results within six months. It can provide information about correlations and magnitudes of density dispersions, as well as, a better mean model. Tentative results from phase one will be useful to the OTV designers while the second phase of incorporating the results into one of the models proceeds.

The other two programs represent different approaches to obtaining more density data. The first approach to obtaining density information would be to re-instrument the STS orbiters and this is, in fact, already underway. However, with their relatively low flight rates and limited reentry paths it will take a long time to gather a significant data base. For this reason a second approach is recommended, the use of a lidar backscatter system to survey the upper atmosphere in the manner described in

Table 3.8-1. Technology Goals — Atmospheric Physics

ITEM	TASKS	STATUS	GOALS
GRAM DEVELOPMENT	• UPDATE GRAM DATA BASE	• ONGOING PROGRAM	• HIGH FIDELITY MODEL OF ATMOSPHERE IN 75–120 KM RANGE INCREASE PREDICTIVE CAPABILITY
SEADS (SHUTTLE ENTRY ATMOSPHERIC DYNAMICS SYSTEM)	• RE-INSTRUMENT STS TO OBTAIN DENSITY GRADIENTS INERTIALLY AND COLLECT DENSITY DATA	• BEING UPGRADED	• ADD HIGH FIDELITY DENSITY AND GRADIENT DATA
LIDAR BACKSCATTER	• DEVELOP LASER SYSTEM FOR LIDAR SURVEY OF UPPER ATMOSPHERE AND COLLECT DENSITY DATA	• SOME LOCAL EXPERIMENTS BEING CONDUCTED	• PROVIDE HIGH FIDELITY DENSITY AND CORRELATION DATA FOR INCREASED FIDELITY IN MODELING AND BETTER PREDICTIVE CAPABILITY

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reference 2-5. This would provide density data accurate to a few percent (±3%) over the entire altitude and latitude range of interest. This could develop into an operational space based system to measure the density variations along the OTV flight path shortly before reentry and allow last minute updates of the GN&C system.

We propose the latter two programs be funded, the first as an interim step to provide limited data over the short term and the second to develop needed measurement tools to provide basic data.

3.8.3 Schedule and Resources

The key technology milestones for the atmospheric physics area are shown in figure 3.8-1. The resources required for the effort are presented in table 3.8-2.

3.9 DATA MANAGEMENT SYSTEM

3.9.1 Objectives

The overall objectives of the DMS development program are improve system reliability and reduce size, weight, and power requirements by achieving the goals listed in table 3.9-1. A fully distributed architecture offers many advantages, including ease of expansion and reduced software application development costs.

3.9.2 Description

The fully distributed architecture will be derived from a distributed system with centralized control. Development of techniques for communicating between processor elements, and for joint decision making capability of processor elements performing independent tasks is required.

The development of IC's implementing token passing protocols should be monitored and the most suitable IC selected and implemented.

The development of a triple modular redundant computer architecture should be continued, and Hamming EDAC circuitry implemented in the memory. Other subtasks are to monitor development of higher density static RAM and EEPROM devices, space qualification of selected microprocessor and memory devices, and the design of custom IC's to reduce the component count.

3.9.3 Schedule and Resources

The key technology milestones for the data management area are shown in figure 3.9-1. The resources required for the effort are presented in table 3.9-2.

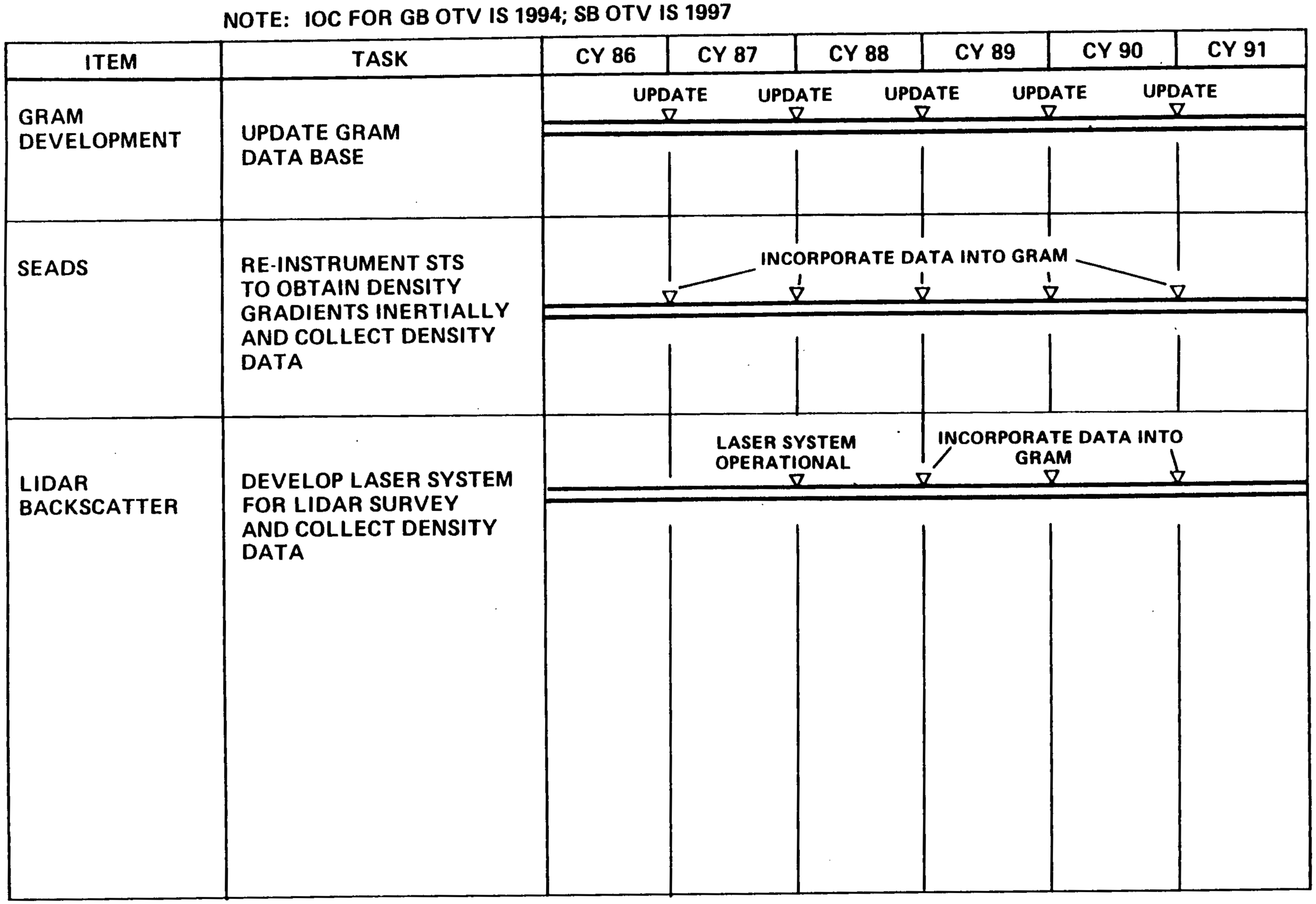

Figure 3.8-1. Atmospheric Physics Schedule

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Table 3.8-2 Atmospheric Physics Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
GRAM Development	• Update GRAM data base	80K	80K	50K	50K	50K	50K
SEADS	• Re-instrument STS to obtain density gradients inertially and collect density data	50K	50K	50K	50K	50K	50K
Lidar Backscatter	• Develop laser system for lidar survey and collect density data	700K	900K	250K	250K	300K	300K
	Total	830K	1,030K	350K	350K	400K	400K

Table 3.9-1. Technology Goals — Data Management Subsystem

ITEM	TASK	STATUS	GOALS
SYSTEM ARCHITECTURE	• DEVELOP DISTRIBUTED ARCHITECTURE	• DISTRIBUTED WITH CENTRALIZED CONTROL BREADBOARD OPERATIONAL IN LATE 1986.	• FULLY DISTRIBUTED DMS ARCHITECTURE
	• DEVELOP FIBER OPTIC BUS TECHNOLOGY	• FIBER OPTIC SERIAL DATA BUS IN DEVELOPMENT, OPERATIONAL IN LATE 1986.	• FIBER OPTIC SERIAL BUS WITH STAR COUPLERS
	• DEVELOP TOKEN PASSING LOGICAL BUS PROTOCOL	• SEVERAL TOKEN PASSING PROTOCOLS HAVE BEEN DEFINED. SUPPORTING HARDWARE IS IN DEVELOPMENT.	• TOKEN PASSING LOGICAL BUS FULLY IMPLEMENTED AS DMS SYSTEM BUS.
REDUNDANCY MANAGEMENT TECHNIQUES	• FAULT TOLERANCE	• A TRIPLE MODULAR REDUNDANT BREADBOARD WITH VOTING WILL BE OPERATIONAL IN LATE 1985.	• DUAL FAULT TOLERANCE USING QUAD MODULAR REDUNDANCY AND VOTING.
	• MEMORY ERROR DETECTION AND CORRECTION	HAMMING EDAC IC's ARE NOW AVAILABLE	• IMPLEMENT DUAL ERROR DETECTION SINGLE BIT ERROR CORRECTION IN ALL INSTRUCTION MEMORY
	• RECONFIGURATION	• DEDICATED SPARING WILL BE DEMONSTRATED IN LATE 1985. POOLED SPARING WILL BE DEMONSTRATED IN LATE 1986.	• DISTRIBUTED N MODULAR REDUNDANCY ARCHITECTURE ALLOWING DEDICATED AND POOLED SPARING.

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Table 3.9-1. Technology Goals — Data Management Subsystem (Continued)

ITEM	TASK	STATUS	GOALS
HARDWARE	• MICROPROCESSOR/ COMPUTER TECHNOLOGY	• MIL-STD-1750A MICROPROCESSOR-BASED COMPUTER IS RADIATION HARD, CURRENTLY OFFERS THROUGHPUT OF 600 KIPS. IT IS NOT CURRENTLY SPACE QUALIFIED.	• SPACE QUALIFIED RADIATION HARD, BIPOLAR TECHNOLOGY, 800 KIPS THROUGHPUT, DAIS MIX. MIL-STD-1750A INSTRUCTION SET ARCHITECTURE COMPUTER
	• RANDOM ACCESS MEMORY	• STATIC RAM CURRENTLY AVAILABLE TO 16K DENSITIES.	• 1024K STATIC RAM, SPACE QUALIFIED
	• NON-VOLATILE PRIMARY MEMORY	• EEPROM CURRENTLY AVAILABLE TO DENSITIES OF 32K. NOT SPACE QUALIFIED	• 512K EEPROM SPACE QUALIFIED
SOFTWARE	• ACQUIRE NECESSARY SOFTWARE TOOLS	• CURRENTLY NOT AVAILABLE EARLY VERSIONS WILL BE AVAILABLE IN LATE 1985.	• MIL-STD-1750A—TARGETED ADA COMPILER
PACKAGING	• REDUCE DMS PACKAGE VOLUME	• CURRENT BREADBOARD DESIGN REQUIRES 15 FT^3.	• 2.5 CUBIC FEET TOTAL DMS VOLUME
	• REDUCE DMS POWER REQUIREMENTS	• 2,340 WATTS FOR BREADBOARD-EQUIVALENT OTV CIRCUITRY.	• 585 WATTS FOR UNMANNED OTV.
	• REDUCE DMS WEIGHT	• 700 LBS FOR BREADBOARD-EQUIVALENT OTV DMS.	• 179 POUNDS TOTAL DMS WEIGHT FOR UNMANNED OTV.

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NOTE: IOC FOR GB OTV IS 1994; SB OTV IS 1997

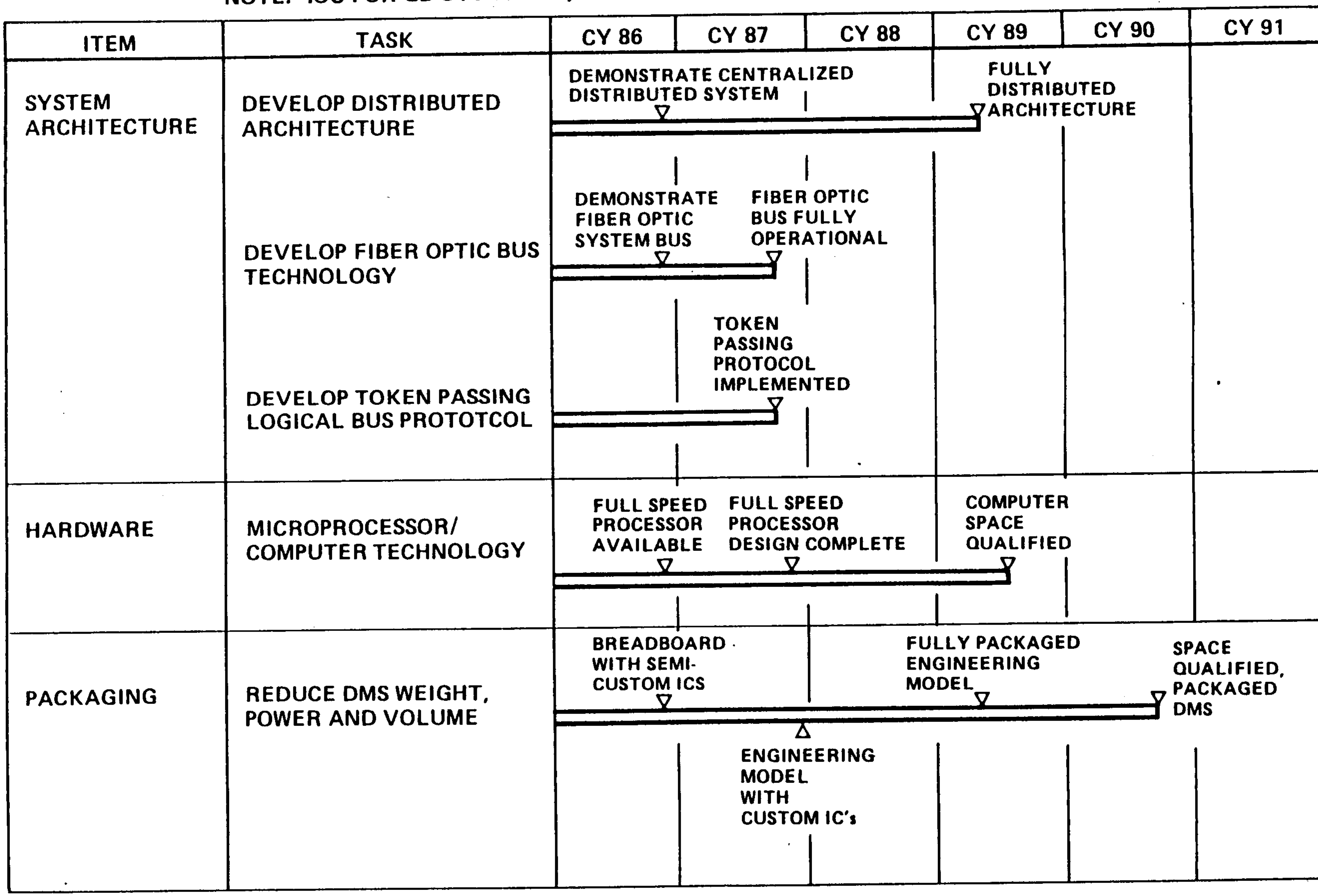

Figure 3.9-1. Data Management System Schedule

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Table 3.9-2 Data Management System Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
System Architecture	• Develop distributed NMR F/T architecture using taken passing system bus	395K	405K	510K	491K	497K	
Packaging	• Reduce package weight, power and volume	301K	387K	513K	483K	489K	
Softwaare	• Develop ADA-based operating system for distributed NMR fault tolerant architecture	407K	312K	298K	326K	273K	
	Total	1,103K	1,104K	1,321K	1,300K	1,259K	

3.10 STATION ACCOMODATIONS

3.10.1 Objective

The objective is to develop the robotics capability, structural design concepts, and assembly techniques and skills needed to minimize on-orbit man-hours required to assemble, store, checkout, and maintain space based OTVs. Storage and handling of cryogenics were discussed in section 3.5.

3.10.2 Description

Status. On orbit replacement of any type of TPS has not been demonstrated. In particular, a method of replacing 'flexible' TPS after it has undergone several thermal cycles has not been postulated. The flexible TPS becomes rigid, and sheds large quantities of ceramic particles when handled. A vacuum-curable adhesive for RSI tiles would be needed to replace them on-orbit.

While automated inspection and fluid management are current technologies on Earth, they have not been applied to space. In particular, inspection must rely on visual techniques, since the vacuum in space prevents the use of ultrasound inspection.

Space assembly techniques are currently being tested in neutral-buoyancy water tanks. They are being pursued in the context of the Space Station program.

Tasks for accomplishing the technology objectives are shown in table 3.10-1, along with goals associated with each task.

Plan. Continue as appropriate neutral buoyancy test. During initial years of Space Station operations implement demonstration test of typical OTV maintenance operations.

3.10.3 Schedule and Resources

The key technology milestones for the station accommodation area are shown in figure 3.10-1. No resource estimate has been made. It should be noted some of the technology needs will be common with other activities performed at the station.

Table 3.10-1. Technology Goals — Station Accommodations

ITEM	TASKS	STATUS	GOALS
SERVICING	• TPS REPLACEMENT	• HAS NOT BEEN DEMONSTRATED	• ON-ORBIT REPLACEMENT OF FLEXIBLE TPS (LIFTING BRAKE) AND RSI TILES
	• AUTOMATION/ ROBOTICS	• NOT DEMONSTRATED IN SPACE ENVIRONMENT	• AUTOMATED INSPECTION AND PROPELLANT TRANSFER REDUCE CREW MANHOURS
ON-ORBIT CONSTRUCTION	• VEHICLE/TPS ASSEMBLY	• SPACE ASSEMBLY TECHNIQUES BEING WATER TESTED	• ON-ORBIT ASSEMBLY CAPABILITY FOR VEHICLE/ ASSEMBLY

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NOTE: IOC FOR GB OTV IS 1994; SB OTV IS 1997

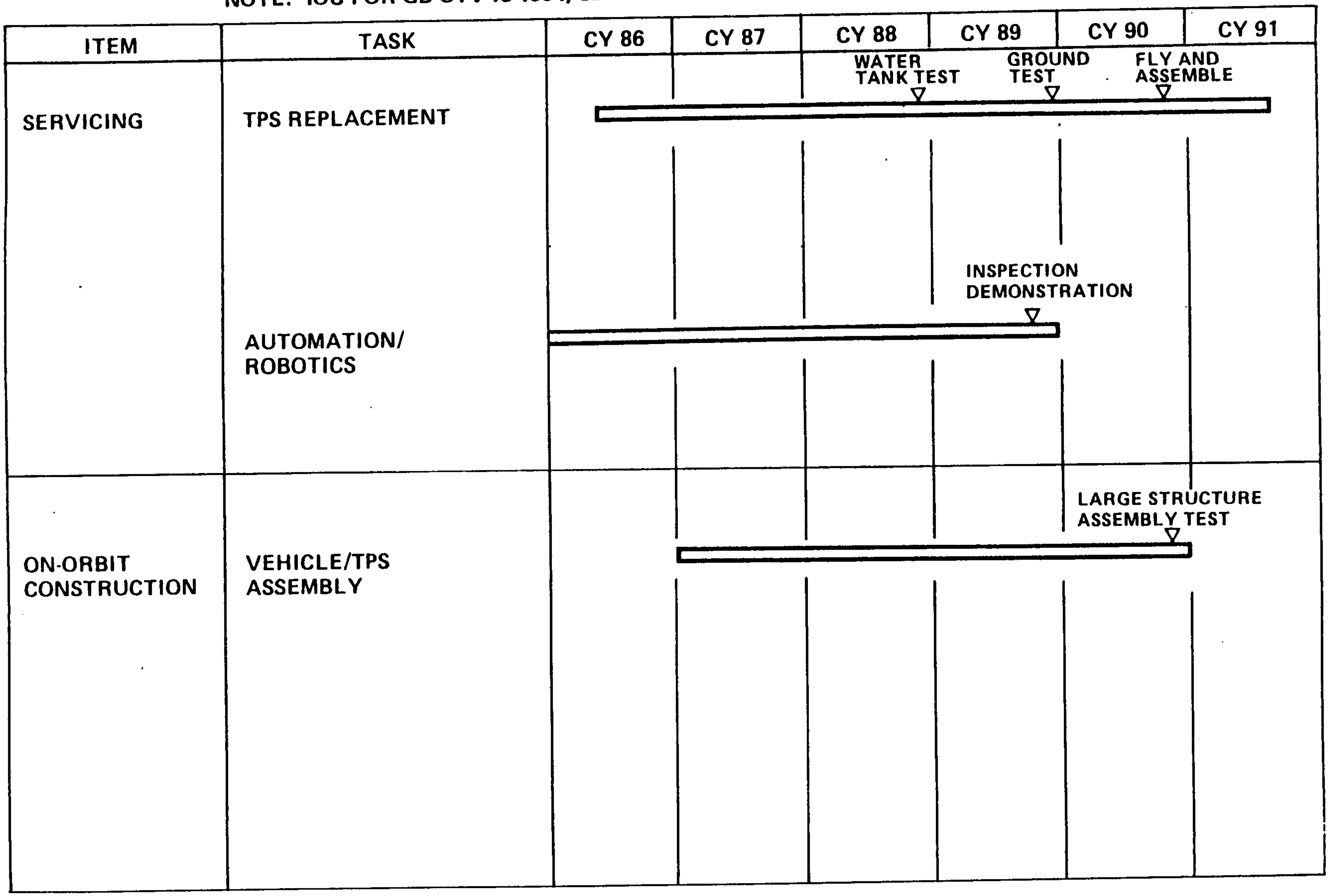

Figure 3.10-1. Station Accommodations Schedule

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3.11 AEROASSISTED FLIGHT EXPERIMENT

3.11.1 Objective

The overall objective of the AFE program is to demonstrate that the technologies required for aeroassisted OTV exist. Specific goals are shown in table 3.11-1. Since most technology advances needed for OTV should occur prior to the first AFE launch to support the proposed schedules, the AFE data are intended primarily to validate and supplement earlier technology development, and not as a substitute for analyses and ground tests.

3.11.2 Description

Status. The AFE progam as now defined by NASA consists of a single flight using a shaped brake configuration launched by the Shuttle. Orbiter type tiles are to be used for the TPS. Data derived from this flight will contribute significantly to validating aerothermal, aerodynamics, atmospheric physics, guidance, and thermal protection data and assumptions used in the design and operations of the vehicle. Originally the AFE flight was scheduled for late 1988. Budgetary constraints subsequently forced the flight out to 1991. Even more recently has been the Shuttle grounding caused by the Challenger accident leaving the flight date for the AFE uncertain.

Plan. In addition to the data obtained from the initial test, at least one other and perhaps two additional flight tests are suggested. Both deal with testing alternate aeroassist devices. This need occurs because the OTV mission needs dictate a brake diameter of at least 40 ft whereas the largest rigid shaped brake possible when launched by the Shuttle is 14.5 ft diameter. Therefore if the OTV is to be ground based and launched by the Shuttle, a different aeroassist devices must be used. Candidates which could be accommodated include an inflatible ballute or a deployed flexible lifting brake. Boeing system level studies have indicated a preference for a ballute device. A third flight could be schedule to demonstrate a deployed lifting brake in order to provide data to select between the two candidates.

Delay of the AFE test as indicated earlier would in turn delay the IOC for the operational OTV until late 1996 or early 1997 if the same relationship between the AFE test and stage PDR is maintained. A higher risk schedule could be implemented however, to allow the OTV to begin operation in 1994. This approach would rely more extensively on ground test data to establish operational characteristics of the aerobraking maneuver using a ballute. The tests would involve establishing aerodynamic, controllability, heat transfer, and thermal protection characteristics.

Table 3.11-1 Technology Goals Aeroassist Flight Experiment

Tasks	Status	Goals
• Establish Requirements	• Very little aero and aerothermal data available in OTV flight regime (Apollo & Project FIRE)	• Demonstrate feasibility of aeroassist OTV
• Design, Fab, & Instrument AFE Vehicle and Support Equipment		• Demonstrate control authority and response of flexible structures
• Conduct Flight Tests and Present Data		• Validate guidance algorithms aero/aerothermal predictions, and TPS performance • Investigate nonequilibrium radiation

Another programmatic approach would have the stage developed for a 1994 IOC but operate as an all propulsive expendable OTV until sufficient AFE test data is available. A preferred approach for the schedule will require further analysis in a future study.

3.11.3 Schedule and Resources

The key technology milestones for the aeroassist flight experiment area are shown in figure 3.11-1. The resources required for the effort are presented in table 3.11-2.

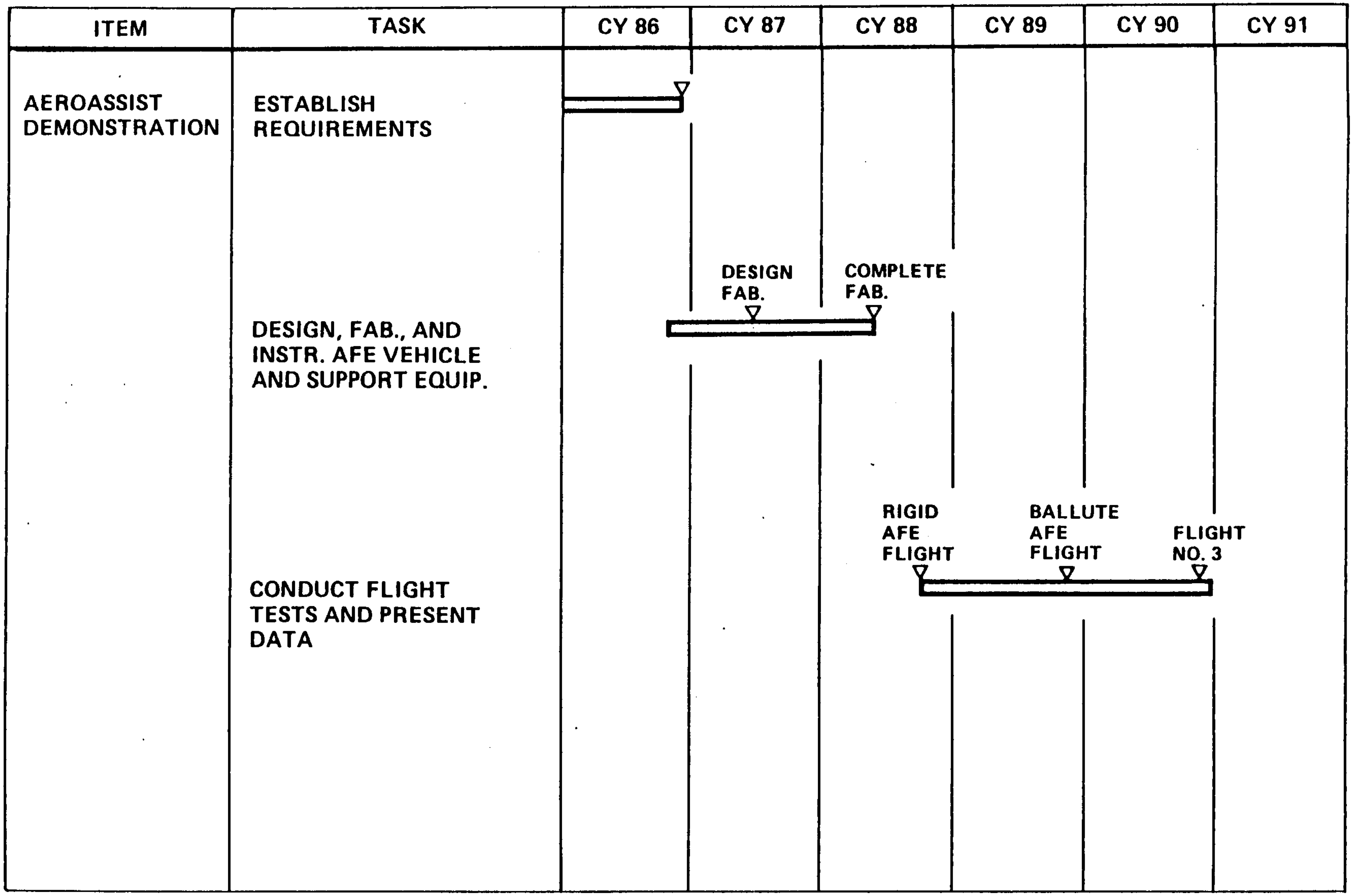

Figure 3.11-1. AFE Flight Experiment

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Table 3.11-2 Aeroassist Flight Experiment Resource Requirements

Cost (1985 Dollars)

Item	Task	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
	• Establish Requirements	700K					
	• Design, Fab, & Inst. AFE Vehicle and Support Equipment		10,000K	5,000K	5,000K		
	• Conduct Flight Tests and Present Data			10,000K	10,000K	5,000K	10,000K
	Total	700K	10,000K	15,000K	15,000K	5,000K	10,000K

4.0 SUMMARY AND CONCLUDING REMARKS

A technology development plan for an advanced reusable OTV has been established. The plan includes an assessment of each technology area and tasks definition and objectives, approach, definition of the work to be done in terms of objectives, specific tasks, tasks definition and objectives, approach, schedules, and resource requirements. An overall summary of the technology activity is presented in table 4.0-1. Total cost of the proposed program is $157 million for a ground based system, and an additional $37 million for addressing technology issues unique to space basing an OTV. The annual funding summary is presented in table 4.0-2. The increments for space basing do not include costs associated with station accommodations, (i.e., robotics, etc.), which have not been defined.

The technology program involving 4 + years is phased so that most of the tasks applicable to a ground based OTV are completed prior to an assumed stage level PDR in 1990 that relates to an IOC of 1994. Results from the aerothermal, aerodynamics and thermal protection efforts are needed as soon as possible, since brake shape, size, and material selections are vitally impacted. Similarly, the atmospheric physics data base should be upgraded as soon as possible, since control authority requirements and TPS design margins are substantially impacted.

Table 4.0-1 Technology Summary

Technology	Concern/Deficiency	Impact (1)	Pre-development Requirements
Aerothermal	Accuracy of Predictions Non-Equilibrium Flows Rarefied Flows	TPS Weight Performance	Analysis Methods Wind Tunnel Tests AFE
Aerodynamics	Accuracy of Predictions Flexible Body Non-equilibrium Flows	Weight Performance	Analysis Methods Wind Tunnel Tests AFE
Thermal Protection	Max Heating Capability Material Limits Coatings Bond Temp	Weight Performance	Material & Coating Development Thermal Tests
Propulsion	Nozzle Performance Life & Maintainability	Weight and Performance Operating Costs	Ground Tests
Cryogenic Fluid Management	Zero/Low "g" Fluid Transfer/Acquisition Venting & Thermal Control	Concept Feasibility Propellant Weight (Space Based OTV)	Orbiter Tests (Low G and Thermal)
Tankage (Propellant storage at Station)	Explosive Rupture from Meteroid/Debris Impact	Safety Structural Weight	Analysis Structural Tests
Guidance	Guidance Algorithms	Mission Data Load Propellant Weight	Optimal Adaptive Guidance
Atmospheric	Atmospheric Density	Risk	Atmospheric Probes
Physics	Variations	TPS and Propellant Weight	Analysis
Data Management	Redundancy Management Performance	Maintainability Weight, Power, Size	Hardware and Software Development and Test
Station Accommodations	Servicing Automation/ Robotics	Cost Crew Ops (SB OTV)	Analysis Ground and Flight Test

(1) All concepts unless specified for SBOTV

Table 4.0-2 Program Resource Requirement Summary

Fiscal Year Cost in Millions of 1985 Dollars

Technology Area	86	87	88	89	90	91
Aerothermal	1.820	1.920	1.695	1.565	1.130	-
Thermal Protection	1.195	1.195	1.145	0.965	-	-
Aerodynamics	0.700	0.800	1.100	0.550	0.500	-
Propulsion	7.400	14.100	17.000	15.000	11.600	8.100
Cryogenic Fluid Management	5.200	6.300	8.000	10.000	5.000	3.000
Cryogenic Tankage	0.290	0.210	-	-	-	-
GN&C	0.300	0.700	0.800	0.400	-	-
Atmospheric Physics	0.830	1.030	0.350	0.350	0.400	0.400
Data Management	1.103	1.104	1.321	1.300	1.259	-
Aeroassist Flight Experiment	0.700	10.000	15.000	15.000	15.000	-
Total	19.538	37.359	46.411	45.130	34.889	11.500

GB OTV TOTAL = $157 million

SB OTV = $157 million plus a supplement of $37 million

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5.0 ,REFERENCES

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